State of California
California Natural Resources Agency
DEPARTMENT OF WATER RESOURCES
Division of Integrated Regional Water Management
North Central Region Office
Water Quality Evaluation Section

Delta Smelt Turbidity Monitoring Project - 2008

Memorandum Report

March 2012

State of California | The Resources Agency

Memorandum

Date: March 7, 2012

To: Eric Hong, Chief EH
North Central Region Office

From: Shaun Philippart, SP
Chief, Water Quality Evaluation Section
Department of Water Resources

Subject: Delta Smelt Turbidity Monitoring Project - 2008

The attached memorandum report, *Delta Smelt Turbidity Monitoring Project – 2008*, presents an overview of the project background, objectives, and methodology utilized in the development of a network of water quality stations as well as an analysis of the collected data. The creation of this network was in response to the establishment of court-mandated turbidity monitoring for the threatened species delta smelt. These stations are collecting water temperature, specific conductance, and turbidity data in an effort to learn more about how changing water quality conditions affect delta smelt survival and movement into the interior of the Sacramento-San Joaquin Delta. This report presents a graphical analysis and a discussion of the data and significant findings for calendar year 2008.

If you have any questions regarding this memorandum report, please contact Shaun Philippart at (916) 376-9661.

Attachment

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DWR 155 (Rev 11/04) | Shaun Phl 3/30/12 | RMNg 3/30/12 | EH 3-30-12 |

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Acronyms and Abbreviations

AWU	Aquatic Weed Unit
CDEC	California Data Exchange Center
cfs	cubic feet per second
CVP	Central Valley Project
Delta	Sacramento-San Joaquin River Delta
DES	[DWR] Division of Environmental Services
DFG	California Department of Fish and Game
DSRAM	Delta Smelt Risk Assessment Matrix
DSWG	Delta Smelt Working Group
DWR	California Department of Water Resources
EDS	Extended Deployment System
FAL	False River near Oakley (water quality monitoring station)
HOL	Holland Cut near Bethel Island (water quality monitoring station)
IQR	interquartile range
JER	San Joaquin River at Jersey Point (water quality monitoring station)
MDM	Middle River at Middle River (USGS station)
MOK	Mokelumne River near Highway 12 (water quality monitoring station)
NCRO	[DWR] North Central Region Office
NTU	nephelometric turbidity units (turbidity measure)
O&M	[DWR] Division of Operations and Maintenance
OMR	Old and Middle River
OBI	Old River near Bacon Island at USGS Pile (water quality monitoring station)
OCAP	Operations Criteria and Plan
PPT	San Joaquin River at Prisoners Point (water quality monitoring station)
PST	Pacific Standard Time
QA/QC	quality assurance and quality control
SWP	State Water Project
TSL	Three Mile Slough near San Joaquin River (water quality monitoring station)
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VCU	Victoria Canal near Byron (water quality monitoring station)
VON	Sacramento River at Verona (water quality monitoring station)
WDL	Water Data Library (database)
WOMT	Water Operations and Management Team
YSI	Yellow Springs Instrument

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Delta Smelt Turbidity Monitoring Project, 2008

Introduction

The Delta Smelt Turbidity Monitoring Project is a response to 2007 court mandates for turbidity monitoring of delta smelt waters. The project initiates investigations to better understand factors that influence delta smelt survival and movement. This project will also benefit model calibrations and provide findings to help guide water operation management decisions. It is anticipated that this project will provide important information to develop a complex network of continuous water quality stations to increase knowledge about the habitat, movement, and migration of delta smelt. Current North Central Region Office (NCRO) turbidity records are presented in tables and figures appended to this report.

Background

In August 2007, U.S. District Judge Oliver Wanger ruled (*NRDC v. Kempthorne et al.* case number 1:05-CV-01207-OWW-GSA) that the 2005 Long-Term Central Valley Project and State Water Project Pumping Operations Criteria and Plan (OCAP) and Biological Opinion were unlawful and inadequate for the protection of the threatened species delta smelt. Judge Wanger also concluded that the supplementary Delta Smelt Risk Assessment Matrix (DSRAM) was in violation of the Administrative Procedure Act, 5 U.S.C. § 705 et seq.

Judge Wanger's court order[1] established several measures that would trigger restrictions to both State Water Project (SWP) and Central Valley Project (CVP) operations in the Sacramento-San Joaquin River Delta (the Delta) to reduce salvage and prevent the extinction of delta smelt.

Judge Wanger's decisions on these measures were based on responses during the hearings from several expert scientists including those from the Delta Smelt Working Group (DSWG). The DSWG consists of knowledgeable experts in the biology of delta smelt and includes members from such agencies as: U.S. Fish and Wildlife Service (USFWS), U.S. Bureau of Reclamation (USBR), U.S. Environmental Protection Agency, California Department of Fish and Game (DFG), and California Department of Water Resources (DWR). The DSWG has the responsibility of reviewing all pertinent data on delta smelt life history and habitat that are used in making recommendations for water project operations.

Based on recent delta smelt studies, scientists from the DSWG discovered significant correlations between several water quality parameters and the presence of delta smelt in the Delta. Those specific water quality parameters included water temperature, specific conductance, and turbidity (Feyrer et al. 2007). Most important to DSWG was the connection between increased turbidity levels during and prior to known delta smelt spawning migration into the interior of the Delta

[1] The final written order by Judge Oliver W. Wanger of the U.S. District Court in Fresno on December 12, 2007, Case 1:05-cv-01207-OWW-GSA is available online at: http://www.earthjustice.org/library/legal_docs/delta-smelt-final-remedy-order.pdf

from mid-December through March. Studies by Lenny Grimaldo, fish biologist at USBR (formerly an environmental scientist in DWR) and currently a member of DSWG, showed a significant increase in delta smelt salvage at the water export facilities during periods of high turbidity (levels of 12 nephelometric turbidity units [NTU] and higher) (Grimaldo et al. 2009). Judge Wanger found this to be significant scientific evidence and in his court order ruled that turbidity levels be addressed as a required control measure in pumping operations to ensure the protection of delta smelt.

Turbidity and Export Pumping Compliance Criteria

As a result of the scientific evidence provided in court, Judge Wanger included in his measures the requirement to monitor turbidity levels by December 25, 2007, at three compliance stations:

Station 1 - Holland Cut near Bethel Island
Station 2 - Victoria Canal near Byron
Station 3 - San Joaquin River at Prisoners Point

If the turbidity levels at any one of these stations exceed 12 NTU and flows measured at Sacramento River at Freeport are less than 80,000 cubic feet per second (cfs), the CVP and SWP must reduce exports for 10 days to ensure that net upstream Old and Middle River flows are less than 2,000 cfs. The pumping restriction can be terminated if any one of these three factors exists:

1) The three-day average of flow in the Sacramento River at Freeport exceeds 80,000 cfs.
2) The Spring Kodiak Trawl survey or export facilities show the presence of spent female delta smelt.
3) The larval delta smelt are recovered at either the CVP or SWP export salvage facility or recovered during the DFG’s 20mm survey; or when water temperature in the Delta reach 12°C.

North Central Region Office Turbidity Stations

The Water Quality Evaluations Section in NCRO installed and operates the following two continuous turbidity monitoring compliance stations as mandated in Judge Wanger’s December 12, 2007, court order:

1) Holland Cut near Bethel Island (HOL)
2) Victoria Canal near Byron (VCU)

The third mandated station, San Joaquin River at Prisoners Point (PPT) is being maintained by DWR’s Division of Environmental Services (DES). Data from that station were reviewed and analyzed in the preparation of this report.

The planning for turbidity station installations began in early August 2007. In March 2007, NCRO established a water quality monitoring station at Victoria Canal near Byron (VCU), which already included temperature, specific conductance, and turbidity. In September 2007, the existing Holland Cut near Bethel Island (HOL) water quality station was retrofitted with turbidity monitoring capabilities. In December 2007, False River near Oakley (FAL) and Old River near

Bacon Island (OBI) were also outfitted with turbidity monitoring instrumentation, in an effort to capture localized turbidity effects caused by Franks Tract.

2008 North Central Region Office Delta Smelt Turbidity Monitoring Updates

Through several meetings in 2007 with staff from DWR, DFG, USBR, U.S. Geological Survey (USGS), the State Water Contractors, and the DSWG, a comprehensive priority list of new water quality station locations was recommended. In 2008, DWR was able to establish several of those stations with the highest priority (Table 1 and Figure 1). In February 2008, USGS, with funding from DWR, added a turbidity probe at the Sacramento River at Verona (VON) water quality and flow station. This station was included in the network of turbidity monitoring stations in order to provide an early warning for turbid pulses moving down the Sacramento River before they reach the interior of the Delta. In April 2008, NCRO completed the installation of two new continuous water quality stations: Mokelumne River near Highway 12 (MOK) and Three Mile Slough near San Joaquin River (TSL). The MOK water quality station was installed to capture turbid pulses coming down the Mokelumne River, which is one of the main tributaries that flow into the central Delta. The TSL water quality station was installed to measure turbid Sacramento River water moving into the interior Delta through the narrow Three Mile Slough that connects to the San Joaquin River. In August 2008, NCRO and USBR established a shared water quality station at San Joaquin River at Jersey Point (JER). This station will monitor turbidity levels in the lower section of the San Joaquin River before it merges with the Sacramento River. VON, MOK, TSL, and JER were installed to improve evaluations of turbidity movement in the Delta and are not compliance stations.

Table 1. Continuous turbidity monitoring station coordinates and date of establishment

Station name	Latitude	Longitude	Date established	Turbidity sensor installed
Victoria Canal near Byron (compliance station)	37º 52' 15.5"	121º 31' 47.9"	30-Mar-07	30-Mar-07
Holland Cut near Bethel Island (compliance station)	38º 0' 59"	121º 34' 54.8"	20-Oct-05	18-Sep-07
San Joaquin River at Prisoners Point (compliance station)	38º 3' 57.6"	121º 33' 43.2"	1-Apr-97	2-Mar-06
Old River at Bacon Island at USGS Pile	37º 58' 12"	121º 34' 15.96"	28-Dec-07	28-Dec-07
False River near Oakley	38º 3' 20.9"	121º 40' 0.8"	20-Oct-05	28-Dec-07
Mokelumne River at near Highway 12	38º 6' 21.96"	121º 34' 15.96"	4-Apr-08	4-Apr-08
Three Mile Slough near San Joaquin River	38º 6' 11.6"	121º 41' 10.0"	10-Apr-08	10-Apr-08
San Joaquin River at Jersey Point	38º 3' 10.8"	121º 41' 16.8"	31-Mar-88	16-Jul-08
Sacramento River at Verona	38º 44' 26.4"	121º 35' 49.2"	13-Feb-08	4-Mar-08

Figure 1 Delta smelt water quality station map

Each continuous water quality station for this project monitors three key parameters that have been regarded as pertinent to delta smelt: temperature (ºC), specific conductance (µS/cm), and turbidity (NTU). Each station's data are telemetered to the California Data Exchange Center (CDEC) for real-time and online access.

On December 15, 2008, the USFWS issued a new Biological Opinion for the CVP and SWP pumping OCAP that addresses additional protection for delta smelt. This new Biological Opinion will further impact SWP and CVP deliveries to cities, farms, and businesses throughout California by an estimated 20 to 50 percent (http://www.fws.gov/sacramento/es/OCAP_BO_actions.htm).

Project Objectives

This project was established for three reasons: (1) To address Judge Wanger's written order of turbidity compliance at Holland Cut near Bethel Island, Victoria Canal near Byron, and San Joaquin River at Prisoners Point; (2) To guide and coordinate the development of a complex network of continuous water quality stations that will provide information as it relates to the survival and movement of delta smelt; and (3) To establish a historical collection of accurate continuous water quality data that can be used for future modeling studies. It is anticipated that data gathered from this project will help state and federal water managers better understand delta smelt populations to minimize possible entrainment and salvage as a result of water export operations.

In accordance with project objectives, NCRO's Water Quality Evaluation Section coordinated with DWR's DES, Division of Operations and Maintenance (O&M), and Bay-Delta Office as well as DFG, USGS, USBR, and the State Water Contractors to develop a proposal to expand monitoring efforts. As a result, a complex network of 19 water quality monitoring stations was identified, from the Suisun Bay to the Sacramento River at Verona. Nine of these proposed water quality stations are currently installed and operational. The purposes of this proposed monitoring network are to provide (1) early warning of upstream turbidity plumes allowing adjustments to SWP/CVP operations to minimize negative impacts to delta smelt migration, and (2) water quality data that can be combined with sampling results for model calibration and studies.

An important aspect to the establishment of new continuous water quality stations connected to this project is the utilization of on-site telemetry equipment. The availability of accessible real-time water quality data will allow water managers at both the SWP and CVP export facilities to make timely decisions on pumping operations. All current stations are providing telemetered data to CDEC and are available for DWR and public access (Table 2).

Table 2. Station Names, CDEC codes, and data availability

WQES Station Name	CDEC Station Name	CDEC code	EC/temp. CDEC data availability	Turbidity CDEC data availability
Victoria Canal near Byron (compliance station)	Victoria Canal near Byron	VCU	3/26/2007-Present	3/26/2007-Present
Holland Cut near Bethel Island (compliance station)	Holland Cut near Bethel Island	HOL	6/16/2006-Present	10/4/2007-Present
San Joaquin River at Prisoners Point (compliance station)	Prisoners Point**	PPT	12/1/2007-Present	3/2/2006-Present
Old River near Bacon Island at USGS Pile	Old River at Bacon Island (USGS)**	OBI	3/27/2008-Present	1/28/2008-Present
False River near Oakley	False River**	FAL	2/9/2007-Present	1/3/2008-Present
Mokelumne River near Highway 12	Mokelumne River @ San Joaquin River**	MOK	6/16/2008-Present	6/16/2008-Present
Three Mile Slough near San Joaquin River	Three Mile Slough at San Joaquin River**	TSL	6/16/2008-Present	6/16/2008-Present
San Joaquin River at Jersey Point (USBR)	Jersey Point**	JER	3/31/1988-Present	7/16/2008-3/15/2010
Sacramento River at Verona	Sacramento River at Verona	VON	2/13/2008-Present	2/13/2008-Present

**Denotes CDEC station name differs from WQES assigned name

The station names in this report are the ones assigned by the NCRO Water Quality Evaluation Section to a particular site and are typically the most location descriptive. Differences in WQES assigned names and CDEC station names exist where, due to the relocation, elimination, or addition of a nearby station, the historical name of a station is rendered inaccurate or obsolete. In these instances, a more descriptive name is assigned to help avoid confusion. Readers should always contact station operators for the most accurate data sets, as data available on CDEC is provisional and has not undergone QA/QC review.

Materials and Methods

Continuous Water Quality Monitoring

NCRO collects water temperature (°C), specific conductance (µS/cm), and turbidity (NTU) data at 15-minute intervals at 1-meter depth by deploying Yellow Springs Instrument (YSI) 6600EDS (Extended Deployment System) mutiparameter sondes at all stations. Continuous data are collected at the following nine stations: Victoria Canal near Byron, Holland Cut near Bethel Island, San Joaquin River near Prisoners Point, Old River near Bacon Island at USGS Pile, False River near Oakley, Mokelumne River near Highway 12, Three Mile Slough near San Joaquin River, San Joaquin River at Jersey Point, and Sacramento River at Verona. DES telemeters the Prisoners Point station independently, and the remaining eight continuous water quality stations are installed with, and operate in conjunction with, existing USGS flow stations. The Jersey Point station telemeters data real-time utilizing a Handar 555 data logger and a GOES satellite radio transmitter. The remaining eight stations are telemetered using an YSI 6091 communication cable that is connected to CR1000 Campbell Scientific Data loggers and an Airlink Raven100 CDMA modem. Through the utilization of a personal computer with LoggerNet software, we are able to access the Airlink modem at the station using the Internet and retrieve real-time data for eventual display on CDEC. For further detailed information on Campbell Scientific instrumentation, visit www.campbellsci.com.

YSI 6600EDS sondes are completely submersible and *in-situ* water quality monitors that operate on eight C-cell alkaline batteries or external solar charged 12V batteries. Data are logged and recorded in each sonde's internal memory. The sondes have the ability to record at different sampling frequencies, but 15-minute intervals were selected for this application. Based on this designated frequency, there are approximately 2,900 recordings per month from each station.

Each sonde utilizes two YSI sensors to record the data desired for this project. The 6560 sensor is used to measure both temperature and specific conductance. The 6136 sensor is used to optically measure turbidity levels in NTUs. To prevent bio-fouling and ensure accuracy, the 6136 Optical Turbidity sensor includes an integrated wiper to clean the optics before each 15-minute reading is recorded. For further detailed information on YSI instrumentation, visit www.ysi.com.

At each monitoring site, a sonde is vertically housed within a 4-inch PVC pipe that is 10 feet in length. The PVC pipes at all four stations are fastened to USGS's fixed cylindrical piles by fitted steel brackets or steel banding equipment. The sonde is suspended using a plastic-coated wire cable and connected to the Campbell data logger using an YSI 6091 communication cable. Each station is installed to ensure the sonde maintains at least a 1-meter depth throughout the tidal cycle. To reduce potential vandalism, pipes are drilled with two sets of longitudinal 0.5-inch holes through the top exposed portion of the pipe. Two long bolts are inserted through the holes and secured with Masterlocks to prevent easy removal of the YSI instrument. The pipes are also drilled with 2.25-inch diameter holes that are spaced 8 inches to 10 inches on center longitudinally along the length of the submerged pipe. This provides ambient flow of water past the sonde's sensors, ensuring accurate data collection.

Quality Assurance and Quality Control

NCRO has developed a complex and thorough methodology of quality assurance and quality control (QA/QC) steps to ensure that the data for this project will be consistently accurate. The QA/QC process begins with the precise calibration of the YSI 6600 sondes during pre-deployment utilizing lab-certified standards to ensure quality data collection during the deployment period. The YSI 6600 sondes are then checked in lab-certified standards after the deployment period as part of our post-deployment process to verify sensor calibration accuracy. The data are then visually and slope inspected through the utilization of NCRO's Hydstra database and discrete measurements collected during field visitations are used to compare data drift. Due to the sensitivity of the 6136 YSI optical turbidity probe, NCRO implemented both a statistical method to detect outliers within data sets, as well as a systematic response protocol if real-time data values are questionable.

Sonde Calibrations

Each sonde is cleaned and calibrated before deployment at NCRO's water quality lab to ensure each probe is operating correctly and recording accurately. The calibration of each sensor is based on YSI's principles of operations. Based on seasonal conditions and observed real-time data, the project maintains a two to three week rotational period as the standard timeframe for exchanging previously deployed sondes with newly calibrated ones. The previously deployed sondes are then brought back to the lab where data files from the deployment are downloaded and the sondes are evaluated through a post calibration procedure. The post calibration procedure is performed to determine errors from probe drift and fouling by checking each individual probe's reading against a calibration standard to confirm the probe's accuracy. The post-calibration occurs the day the sonde is exchanged and before the sonde is cleaned. The readings for each probe during the post-deployment are recorded and rated as excellent, good, fair, or poor based on the deviation from the calibration standard according to the USGS technical report, "Guidelines and Standard Procedures for Continuous Water Quality Monitors-Station Operation, Record Computation, and Data Reporting"(Wagner et al. 2006).

Data files recovered from the previously deployed sondes are then uploaded to the Hydstra database where NCRO staff can perform QA/QC verification before data populates the online accessible Water Data Library database (WDL http://wdl.water.ca.gov). Data are also available online in real-time on CDEC, but without staff quality assurance and quality control verification (http://cdec.water.ca.gov).

Discrete Monitoring

Field data are collected discretely at all stations during every station visit for quality assurance purposes. Field instruments used include an YSI-63 Handheld that measures water temperature, pH, and specific conductance; and a HACH 2100P turbidimeter for measuring turbidity in NTU. Field instruments used for discrete data collection are calibrated to the manufacturer's specifications before use. Data from the same date and time from both the handheld instruments and sondes are recorded on a Field Sheet and compiled into a spreadsheet for comparison.

Turbidity Statistical Outlier Identification Procedure

The 6136 YSI turbidity probe's optical lens can be occasionally obstructed by debris, aquatic organisms, fish, sediment, a malfunctioning turbidity wiper, etc. If the lens is blocked or partially blocked while a reading is being taken, the resulting value will not reflect the "true" ambient water quality conditions. Due to these random anomalies in the turbidity data, staff implemented a statistical method to identify extreme outliers and remove them from the daily mean and range calculations.

The YSI 6600 sonde takes readings every 15 minutes and collects a total of 96 data points daily. Outliers for each set of 96 data points are identified by using a box plot, where an extreme outlier is defined as an observation that falls more than 10 times the interquartile range (IQR) above the upper quartile or more than 10 times the IQR below the lower quartile. The construction of a box plot is performed by ordering the data from lowest to highest and determining the lower (first) quartile (Q1), the median, and the upper (third) quartile (Q3). Q1 is the median of the lower 50% of the data, and Q3 is the median of the upper 50% of the data (i.e., if there are 96 data points arranged from lowest to highest then Q1 (96*.25) would be value number 24 and Q3 (96*.75) would be value number 72.) The IQR can then be calculated by subtracting Q3 (value number 72) from Q1 (value number 24). For the data set, outliers are defined as values exceeding 10*(value number 72 – value number 24) above Q3 or below Q1.

Project Response QA/QC Protocols

For the purpose of ensuring consistent and accurate data collection at our delta smelt compliance stations, we have developed the following protocol:

To detect malfunctions, inaccuracies and spurious data, a four-step QA/QC program with appropriate checks and balances has been established:

1) Discrete readings and/or samples are hand-collected at the site, using independent portable instruments for the field readings, or collection bottles for grab samples. Grab samples are then taken in for laboratory analysis at DWR's Bryte Lab. These readings and sample results are then used to ensure that the values measured by the remote sensor are representative of the overall conditions at the site and to ensure that the remote sensor is operating properly.
2) Post-deployment calibration analysis of the sonde is done immediately after it has been taken back to the lab to ensure that the sensor was reading accurately in the field.
3) Data are screened as they are compiled and processed, which include identification of data outliers (to ensure that the data are within preset ranges based on sensor sensitivity and known physical limits), statistical analysis and flagging of outliers (checks involve statistical analysis to ascertain that the data are within two to three standard deviations of a running mean), and comparison with discrete sample data and post-deployment calibration data to detect spurious trends.
4) A daily check of the data is made as it is displayed on CDEC by looking for obvious errors, data gaps, and omissions. Results of the daily data checks are displayed on a dry-erase board in the office and are transferred to a permanent Excel spreadsheet at the end of the week. The response to finding errors in the data is outlined below.

The QA/QC procedures for identifying and responding to malfunctions, inaccuracies, and spurious data observed on CDEC, have been established as follows:

Step 1 If the daily CDEC checks show that the compliance stations are functioning properly and the data values are within the expected range, the check will be noted on the office daily board and the spreadsheet. No further action is required.

Step 2 If the daily CDEC checks show that the compliance stations are functioning properly, with the exception of a few isolated spikes lasting no longer than 30 minutes, and the rest of the data values are within the expected range, the spikes will be noted on the spreadsheet. No further action is required.

Step 3 If the daily CDEC checks show that the compliance stations are displaying several spikes lasting longer than 30 minutes, the station will be placed on a “watch” basis and the station data values will be checked on an hourly basis until the data values are within the expected range. If the data values return to the expected range, no further action is required. If the data values do not return to the expected range, then proceed to Step 4.

Step 4

a. If the daily CDEC checks show that the compliance station(s) is reporting values outside of the expected range and these spikes are continuous and have lasted for more than two contiguous hours, staff will be contacted immediately. Staff will deploy to the station site; and the sonde will be removed from the site and replaced with a newly calibrated sonde. When replacing the sonde, discrete measurements will be made using handheld instruments to confirm accuracy of the removed and newly deployed sondes. If field measurements show values for turbidity exceed 12 NTU, grab samples will also be taken and sent to Bryte Lab for analysis.

b. If the daily CDEC checks show that the compliance station(s) has stopped recording data, efforts will be made to first remotely check the telemetry device to determine if it is a program error. Contact will also be made with staff that maintains the operation of the CDEC site, to determine if the site is malfunctioning. If the data reporting stream can be corrected by remote re-programming, or corrected via CDEC staff, no further action is required. If this action fails to correct the problem, staff will be contacted; and the station sonde will be removed from the site and replaced with a newly calibrated sonde. When replacing the sonde, discrete measurements will be made using handheld instruments to confirm accuracy of the removed and newly deployed sonde. If the discrete measurements show values for turbidity exceed 12 NTU, grab samples will also be taken and sent to Bryte Lab for analysis.

The Office Daily Board is maintained in the NCRO Water Quality Evaluation Section. This information is planned to be posted on the NCRO Web site, but currently it is available only in spreadsheet form upon request. Requests for this data should be submitted to Tyler Salman (tsalman@water.ca.gov).

Data Summary Narrative

Data summary narratives in this section refer to tables and figures appended to this report. Statistical summary of 2008 water temperature, specific conductance, and turbidity data are listed by station in Table 3, Table 4, and Table 5. Water temperature data for each station are in Figure 2 and Figure 3; specific conductance data, Figure 4 and Figure 5; and turbidity data, Figure 6 and Figure 7. Note: Data from Sacramento River at Verona was not plotted because it is not located in the legal boundary of the Sacramento-San Joaquin Delta.

Victoria Canal near Byron

Water temperature data has been collected at 15-minute intervals at Victoria Canal near Byron (VCU) since March 30, 2007. In 2008, water temperature reached a maximum of 26.87 ºC on July 9 at 17:45 Pacific Standard Time and a minimum of 6.94 ºC on January 1 at 7:45 PST. Water temperature for 2008 had an overall standard deviation from the mean of 5.89 ºC (Table 3 and Figure 2). The water temperature patterns followed typical seasonal trends, with the highest temperatures occurring in the summer and the lowest temperatures in the late fall and winter.

Specific conductance data have been collected at 15-minute intervals at this site since March 30, 2007. In 2008, specific conductance reached a maximum of 750.4 µS/cm on January 29 at 9:30 PST and a minimum of 247.4 µS/cm on July 15 at 13:30 PST. Specific conductance for 2008 had an overall standard deviation from the mean of 77.94 µS/cm (Table 3 and Figure 4). Specific conductance values were highest in the winter and spring and lowest in the summer and fall months.

Turbidity data at 15-minute intervals have been collected at this site since March 30, 2007. In 2008, turbidity reached a maximum of 32.89 NTU on February 22 at 7:15 PST and a minimum of 0.40 NTU on October 30 at 13:29 PST. Turbidity data collected for 2008 had an overall standard deviation from the mean of 4.53 NTU (Table 3 and Figure 6). Turbidity values were the highest during the spring and summer months. In the spring, turbidity values increased with seasonal precipitation trends and wind events, which increase suspended sediments within the water column. Summer increases in turbidity values were correlated with increased biological activity in the water column (i.e., algal blooms). Turbidity values were lowest during the fall and early winter months when cold temperatures reduce biological activity and there is an absence of precipitation to introduce suspended sediments to the water column.

Holland Cut near Bethel Island

Water temperature data have been collected at 15-minute intervals at Holland Cut near Bethel Island (HOL) since September 19, 2005. In 2008, water temperature reached a maximum of 26.02 ºC on August 29 at 15:45 PST, and a minimum of 6.78 ºC on January 1 at 9:45 PST. The water temperature data for 2008 had an overall standard deviation from the mean of 5.57 ºC (Table 3 and Figure 2). The water temperature patterns followed typical seasonal trends, with the highest temperatures occurring in the summer and the lowest temperatures in the late fall and winter.

Specific conductance data for 2008 reached a maximum of 1,146 µS/cm on September 9 at 21:45 PST and a minimum of 270 µS/cm on February 14 at 6:30 PST. The specific conductance data for 2008 had an overall standard deviation from the mean of 226.61 µS/cm (Table 3 and Figure 4). Specific conductance values were the highest in late summer through the winter and lowest during the months of spring.

Turbidity data for 2008 reached a maximum of 364.9 NTU on February 14 at 6:15 PST and a minimum of 1.70 NTU on November 8 at 7:30 PST. The turbidity data for 2008 had an overall standard deviation from the mean of 15.32 NTU (Table 3 and Figure 6). Turbidity levels remained low throughout the fall months until significant changes in tidal fluctuations, wind events, and precipitation increased turbidity levels to their highest levels in the spring months of February through May.

Old River near Bacon Island at USGS Pile

Water temperature data have been collected at 15-minute intervals at the Old River near Bacon Island at USGS Pile (OBI) station since April 4, 2000. Water temperature data from December 2008 reached a maximum of 25.94 ºC on July 9 at 17:00 PST and a minimum value of 6.71 ºC on January 2 at 7:30 PST. The temperature data from December 2008 resulted in a standard deviation from the mean of 5.62 ºC (Table 3 and Figure 2). Temperature data represented a normal seasonal trend with low temperatures occurring in both the winter months of December and January.

Specific conductance data from December 2008 reached a maximum of 942.80 µS/cm on September 14 at 4:00 PST and a minimum value of 272.0 µS/cm on July 4 at 8:15 PST. The specific conductance data from 2008 resulted in a standard deviation from the mean of 185.59 µS/cm (Table 3 and Figure 4). Specific conductance levels within Old River peaked toward the end of December, and maintained a downward trend through January possibly due to increased freshwater flowing into the Delta.

Turbidity data from 2008 resulted in a maximum value of 117.50 NTU on February 14 at 9:45 PST and a minimum value of 1.40 NTU on both November 24 at 4:30 PST and December 20 0:00 PST. Turbidity data collected in 2008 resulted in a standard deviation from the mean of 9.46 NTU (Table 3 and Figure 6). Turbidity levels throughout the months of December and January maintained stable levels, until a significant storm event on January 4 caused a significant plume of turbid water to move down Old River.

False River near Oakley

Water temperature data have been collected at 15-minute intervals at False River near Oakley (FAL) since October 20, 2005. In 2008, water temperature reached a maximum of 24.37 ºC on July 8 at 15:30 PST and a minimum of 6.79 ºC on December 19 at 4:15 PST. The water temperature data for 2008 had a standard deviation from the mean of 5.12 ºC (Table 3 and Figure 2). Water temperatures dropped through December and into January and reflected the typical seasonal trends of the lowest data values occurring in the winter months.

Specific conductance data in 2008 reached a maximum of 6,100.6 µS/cm on December 13 at 16:45 PST and a minimum of 239.60 µS/cm on June 30 at 11:30 PST. The specific conductance data for December 2008 resulted in a standard deviation from the mean of 608.11 µS/cm (Table 3 and Figure 4). Specific conductance values remained high in December and into January, fluctuating greatly with tidal movement. As the tides fluctuated and increased precipitation caused more freshwater to flow into the Delta, the specific conductance levels began to drop significantly in mid-February.

Turbidity data from 2008 reached a maximum of 90.0 NTU on February 2 at 23:45 PST and a minimum of 2.90 NTU on November 6 at 5:45 PST. Turbidity data from 2008 had an overall standard deviation from the mean of 11.24 NTU (Table 3 and Figure 6). Turbidity maintained stable levels through the end of December until significant increases in both wind and precipitation on January 4 brought the first turbid pulses down the main tributaries into the interior Delta.

Sacramento River at Verona

Water temperature, specific conductance, and turbidity data have been collected at 15-minute intervals at the Sacramento River at Verona (VON) site since February 13, 2008. USGS installed this new water quality monitoring station in response to the need for a more comprehensive turbidity network as it relates to delta smelt migration and the court order by Judge Wanger. The station provides an early warning when turbid pulses from precipitation begin moving down the Sacramento River into the interior of the Delta.

In 2008, water temperature reached a maximum daily average of 25.80 ºC on July 8 and a minimum daily average of 7.00 ºC on December 16. The water temperature data for 2008 had a standard deviation from the mean of 4.90 ºC (Table 4). Temperature data represented a normal seasonal trend with low temperatures occurring in the late fall and winter months.

Specific conductance data in 2008 reached a maximum daily average of 245.00 µS/cm on November 11 and a minimum daily average of 93.00 µS/cm on June 19. The specific conductance data for 2008 resulted in a standard deviation from the mean of 31.26 µS/cm (Table 4). Specific conductance values were the highest in the months November and December. Specific conductance levels were lowest in the spring and summer months with increased freshwater inflow due to precipitation and annual snowmelt.

Turbidity data from 2008 reached a maximum daily average of 49.00 NTU on April 12 and a minimum daily average of 2.60 NTU on August 5. Turbidity data from 2008 had an overall standard deviation from the mean of 8.23 NTU (Table 4). Turbidity followed typical seasonal trends with highest levels during the spring due to precipitation runoff into the Sacramento River and lowest during the summer due to annual snowmelt.

Three Mile Slough near San Joaquin River

Water temperature, specific conductance, and turbidity data have been collected at 15-minute intervals at Three Mile Slough at San Joaquin River (TSL) site since April 10, 2008. NCRO staff installed this new water quality monitoring station in response to the need for a more comprehensive turbidity network as it relates to delta smelt migration and the court order by Judge Wanger. Three Mile Slough connects the lower part of the Sacramento River to the San Joaquin River and creates a passageway for fish migration and turbid water in and out of the central Delta.

In 2008, water temperature reached a maximum of 23.86 ºC on August 29 at 15:00 PST and a minimum of 7.74 ºC on December 27 at 8:15 PST. The water temperature data for 2008 had a standard deviation from the mean of 3.92 ºC (Table 4 and Figure 3). Temperature data represented a normal seasonal trend with low temperatures occurring in the late fall and winter months.

Specific conductance data in 2008 reached a maximum of 4,984.30 µS/cm on December 13 at 17:15 PST and a minimum of 201.0 µS/cm on June 26 at 17:15 PST. The specific conductance data for 2008 resulted in a standard deviation from the mean of 532.92 µS/cm (Table 4 and Figure 5). Specific conductance values were the highest in the fall and winter months and fluctuated throughout the year with tidal movement. The lowest specific conductance values were observed in the spring due to freshwater inflow from the Sacramento River.

Turbidity data from 2008 reached a maximum of 35.20 NTU on June 4 at 6:45 PST and a minimum of 3.20 NTU on December 7 at 6:15 PST. Turbidity data from 2008 had an overall standard deviation from the mean of 5.30 NTU (Table 4 and Figure 7). Turbidity followed a typical seasonal trend with highest levels during the spring and again during the summer months due to increased biological activity in the water column.

Mokelumne River near Highway 12

Water temperature, specific conductance, and turbidity data have been collected at 15-minute intervals at Mokelumne River near Highway 12 (MOK) since April 4, 2008. NCRO staff installed this new water quality monitoring station in response to the need for a more comprehensive turbidity network as it relates to delta smelt migration and the court order by Judge Wanger. The Mokelumne River is one of three main tributaries that flows into the Delta and is a significant source of turbidity entering the Delta annually.

In 2008, water temperature reached a maximum of 25.38 ºC on July 18 at 18:30 PST and a minimum of 7.25 ºC on December 23 at 8:15 PST. The water temperature data for 2008 had a standard deviation from the mean of 4.42 ºC (Table 4 and Figure 3). Temperature data represented a normal seasonal trend with low temperatures occurring in the late fall and winter months.

Specific conductance data in 2008 reached a maximum of 648.69 µS/cm on December 25 at 16:00 PST and a minimum of 130.00 µS/cm on June 18 at 10:15 PST. The specific conductance data for 2008 resulted in a standard deviation from the mean of 43.51 µS/cm (Table 4 and Figure 5). Specific conductance values were the highest in December and fluctuated with tidal movement. As the tides fluctuated and freshwater flow increased into the Delta due to more precipitation, the specific conductance levels dropped significantly.

Turbidity data from 2008 reached a maximum of 43.10 NTU on June 4 at 1:00 PST and a minimum of 1.40 NTU on October 21 at 18:15 PST. Turbidity data from 2008 had an overall standard deviation from the mean of 4.03 NTU (Table 4 and Figure 7). Turbidity levels followed a typical seasonal trend with highest levels occurring during the spring and lowest levels during the fall and winter months.

San Joaquin River at Jersey Point

Water temperature and specific conductance data have been collected at 15-minute intervals at San Joaquin River at Jersey Point (JER) since March 31, 1988, by USBR. On July 16, 2008, NCRO staff collaborated with USBR to install new YSI water quality monitoring equipment at this station that included a 6136 Optical Turbidity sensor in response to the need for a more comprehensive turbidity network as it relates to delta smelt migration and the court order by Judge Wanger.

In 2008, water temperature reached a maximum of 24.14 ºC on September 7 at 16:45 PST and a minimum of 7.78 ºC on December 26 at 23:00 PST. The water temperature data for 2008 had a standard deviation from the mean of 2.91 ºC (Table 4 and Figure 3). Temperature data represented a normal seasonal trend with low temperatures occurring in the late fall and winter months.

Specific conductance data in 2008 reached a maximum of 7,319.00 µS/cm on December 13 at 16:45 PST and a minimum of 464.70 µS/cm on November 6 at 6:00 PST. The specific conductance data for 2008 resulted in a standard deviation from the mean of 827.94 µS/cm (Table 4 and Figure 5). Specific conductance values were the highest in the fall and winter months due to reduced freshwater outflow from the Sacramento River.

Turbidity data from 2008 reached a maximum of 28.30 NTU on December 13 at 2:30 PST and a minimum of 2.92 NTU on December 11 at 23:15 PST. Turbidity data from 2008 had an overall standard deviation from the mean of 2.92 NTU (Table 4 and Figure 7). Turbidity levels were highest during the observed late summer months and lowest during the fall and winter months.

San Joaquin River at Prisoners Point

Water temperature and specific conductance data collection at 15-minute intervals have been collected at San Joaquin River at Prisoners Point (PPT) since April 1, 1997. This station was installed and is operated by DES. This station began collecting 15-minute turbidity data on March 2, 2006, and became one of the three court-ordered turbidity compliance stations in December 2007 based on Judge Wanger’s decision. The Prisoners Point station helps to capture the changing water quality conditions in the lower San Joaquin River as it enters the central portion of the Delta.

In 2008, water temperature reached a maximum of 25.67 ºC on July 10 at 18:00 PST and a minimum of 7.56 ºC on February 5 at 7:00 PST. The water temperature data for 2008 had a standard deviation from the mean of 4.94 ºC (Table 5 and Figure 3). Temperature data represented a normal seasonal trend with low temperatures occurring in the late fall and winter months.

Specific conductance data in 2008 reached a maximum of 591 µS/cm on December 26 at 5:00 PST and a minimum of 193 µS/cm on July 10 at 2:00 PST. The specific conductance data for 2008 resulted in a standard deviation from the mean of 76.03 µS/cm (Table 5 and Figure 5). Specific conductance values were the highest in December and fluctuated with tidal movement. As freshwater inflow increased into the interior Delta from the Sacramento and San Joaquin rivers due to spring precipitation, the specific conductance levels dropped significantly throughout the spring and summer months.

Turbidity data from 2008 reached a maximum of 45.00 NTU on February 3 at 16:00 PST and a minimum of 0.3 NTU on November 29 at 8:00 PST. Turbidity data from 2008 had an overall standard deviation from the mean of 5.32 NTU (Table 5 and Figure 7). Turbidity levels remained low throughout the fall and winter months, but levels increased with significant changes in spring tidal fluctuations, wind events, and precipitation.

Significant Findings

These findings included a review of wind, wave, flow, and tidal conditions and the use of discrete monitoring investigations to confirm continuous water quality monitoring results. Also, the preceding environmental conditions were evaluated in connection with NCRO- and DES-measured turbidity levels at the established continuous monitoring stations to explain the findings.

In addition, NCRO obtained and analyzed delta smelt salvage data from both the federal and State fish collection facilities as well as *Egeria densa* treatment data by the California Department of Boating and Waterways (DBW) to identify relationships between these species and measured turbidity levels at NCRO and O&M continuous water quality stations.

Turbidity Levels during Compliance Period

The court-ordered compliance period begins each year on December 25 and continues through January 15. If turbidity levels during the compliance period rise above 12 NTU at any of the three official compliance stations, SWP and CVP must stop pumping for 10 days. Turbidity data are being collected at all current continuous water quality monitoring stations at 15-minute intervals. Data figures are appended to this report. Note: Since the compliance period spans over two calendar years, both the 2007-08 and 2008-09 compliance periods are discussed.

Turbidity data are being collected using the YSI 6136 Optical Turbidity Probe, which records data using the nephelometric method. The nephelometric measurement is recommended for its precision, sensitivity, and applicability over a wide turbidity range [Nephelometric measurement is reported as nephelometric turbidity units (NTU)] (APHA 2005).

2007–2008 Turbidity Compliance Period

During the 2007–2008 compliance period, turbidity data at Holland Cut near Bethel Island averaged 12.50 NTU; it reached a maximum value of 66.4 NTU on December 25, 2007, at 5:30 PST and minimum value of 4.00 NTU on December 25, 2007, at 2:15 PST. Victoria Canal near Byron turbidity data averaged 7.82 NTU and reached a maximum value of 27.75 NTU on January 9, 2008, at 7:30 PST and a minimum value of 3.06 NTU on December 25, 2007, at 1:00 PST. Prisoners Point turbidity data averaged 11.58 NTU and reached a maximum value of 38.0 NTU on January 12, 2008, at 17:00 PST and a minimum value of 3.9 NTU on January 2, 2008, at 6:00 PST (Figure 8).

Holland Cut near Bethel Island was the first of the three compliance stations to record a value greater than or equal to 12 NTU on December 25, 2007, at 4:15 PST. This resulted in the curtailment of pumping for 10 days in order to protect delta smelt from being pulled into the federal and State water project export facilities. The Prisoners Point station did not record a value greater than or equal to 12 NTU until January 4, 2008, at 13:00 PST; and Victoria Canal near Byron, not until January 4, 2008, at 14:45 PST. During the 2007–2008 compliance period, Holland Cut near Bethel Island recorded 844 15-minute readings greater than or equal to 12 NTU; Victoria Canal near Byron recorded 443 values; and Prisoners Point recorded 723 readings (Figure 9).

2008–2009 Turbidity Compliance Period

During the 2008–2009 compliance period, turbidity data at Holland Cut near Bethel Island averaged 4.63 NTU and reached a maximum value of 19.7 NTU on December 25, 2008, at 14:30 PST and minimum value of 2.6 NTU on December 31, 2008, at 3:00 PST. Turbidity data at Victoria Canal near Byron averaged 3.18 NTU and reached a maximum value of 7.5 NTU on January 12, 2009, at 15:44 PST and a minimum value of 1.5 NTU on January 5, 2009, at 6:00 PST. Turbidity data at Prisoners Point averaged 7.32 NTU and reached a maximum value of 13.2 NTU on January 2, 2009, at 17:00 PST and a minimum value of 2.3 NTU on December 31, 2008, at 6:00 PST (Figure 10).

The Prisoners Point station was the first of the three compliance stations in the 2008–2009 compliance period to record a value greater than or equal to 12 NTU, a value of 12.5 NTU on December 25, 2008, at 12:00 PST. The Holland Cut near Bethel Island station recorded its first value greater than or equal to 12 NTU, a value of 13.4 NTU on December 25, 2008, at 13:15 PST and Victoria Canal did not record a single value greater than or equal to 12 NTU. During the 2008-2009 compliance period Holland Cut near Bethel Island recorded a total of seventeen 15-minute readings greater than or equal to 12 NTU, and Prisoner’s Point recorded four readings greater than or equal to 12 NTU (Figure 11).

Wind/Storm Event December 25, 2008

On December 25, 2008, the San Joaquin Valley experienced a high-wind event that caused increased turbidity levels above 12 NTU at Holland Cut near Bethel Island. Prior to the high wind event, December turbidity levels at this site averaged 3.89 NTU, but levels began to increase on December 25, 2008, at 12:15 PST and maintained high levels for a six-hour window with a turbidity average of 13.2 NTU until 18:15 PST and a high of 19.7 NTU (Figure 12). NCRO staff analyzed 15-minute wind speed and direction data that were acquired from the Antioch gauge station. Wind speed data during December 25, 2008, began to increase at 9:45 PST and averaged 11.6 mph until 18:15 PST. The highest recorded 15-minute wind speed value during this time period was 15 mph at 12:00 PST (Figure 13). Wind direction was dominantly West South West; especially during the highest wind speeds of December 25.

Franks Tract was identified as a localized turbidity source at Holland Cut near Bethel Island in 2008 due to its large shallow expansive nature and its vulnerability to mixing due to wind and wave action. Therefore, flow conditions at Holland Cut were analyzed to determine a correlation between increased turbidity and changes in the flood and ebb tides. The highest turbidity values on December 25 occurred during a flood tide. During the flood tide, turbid water, created by the wind induced waves in Franks Tract, is drawn into Holland Cut causing an increase in observed NTU values at this water quality station.

In December 2007, NCRO staff installed two new YSI 6136 optical turbidity probes at the continuous water quality stations Old River at Bacon Island (OBI) and False River near Oakley (FAL) in response to a similar high wind event that occurred in 2007. These two stations were installed to better understand the movement of turbid water in and out of Franks Tract due to changing local wind, wave, and tidal conditions.

The False River station is located northwest of Franks Tract and monitors any turbid water flowing into Franks Tract from the Sacramento River (Figure 1). The False River station also helps monitor any turbid water moving out of Franks Tract on an ebb-tide that may have been caused by a localized wind event. The turbidity levels for December 2008 at False River averaged 6.92 NTU prior to the high wind event that occurred on December 25, 2008. On December 25, 2008, turbidity levels averaged 11.17 NTU with an increase to 14.4 NTU at 15:00 PST during the ebb-tide (Figure 14).

The Old River near Bacon Island station is located upstream in Old River and monitors turbid water that moves south passed Holland Cut during a flood tide (see Figure 1). The turbidity levels in December 2008 averaged 3.38 NTU prior to the high wind event on December 25. The turbidity levels on December 25 averaged 3.59, and no observed NTU values were over 12 NTU during the entire tidal cycle (Figure 15).

Effects of *Egeria Densa* Treatment in Franks Tract on Turbidity

DBW has been controlling the growth of the aquatic invasive plant *Egeria densa* in the Delta since 2001. *Egeria densa* was first identified in the Delta an estimated 40 years ago, and it currently infests thousands of acres. *Egeria densa* grows in thick subsurface mats that act like filters collecting sediments and floating particles in the water column. This filtering causes dramatic declines in turbidity levels throughout the Delta and promotes organic loading in shallow, flooded islands and sloughs. These heavy mats can also slow water movement that effect Delta flow regimes (DBW 2006). All these factors caused by *Egeria densa* can directly affect those threatened and endangered species that inhabit the Delta, including salmonids and delta smelt. These effects include changes in channel habitat for migration and alterations in the food-web.

Franks Tract has been the main treatment area for *Egeria densa* since the control program was initiated in 2001. With the installation of the Holland Cut near Bethel Island turbidity compliance station in 2007 and the known filtering effects that *Egeria densa* has on sediments in the water column, NCRO analyzed timing and location data for the removal of the invasive aquatic plant during 2007 and 2008 in Franks Tract.

Franks Tract encompasses a total of 3,055.55 surface acres of water in the central region of the Delta. DBW has split that acreage into three site locations for treatment purposes; they include: Site 173 (957.88 acres), 174 (1676.78 acres), and 175 (420.89 acres) (Figure 16). DBW increased its treatment area significantly between 2006 and 2007. In 2006, DBW treated only 140 acres of Site 173 beginning in April. And in 2007 and 2008, the treatment area included site locations within 173, 174, and 175, and totaled some 2,570 acres of Franks Tract.

During the treatment seasons of 2007, DBW Aquatic Weed Unit (AWU) achieved a 13% reduction in bio-volume and a 5% reduction in bio-cover. In the 2008 season, AWU applied the herbicides in some new locations; this resulted in a reduction of 8.9% in bio-volume and a 45.3% reduction in bio-cover. With this increased success, DBW did not treat Franks Tract in 2009 and does not plan on treating again until 2011 (Newman pers. comm.).

Seasonal variation in the treatment areas and reduction success of *Egeria densa* in Franks Tract should be reflected in the overall turbidity data collected at stations that measure the water moving in and out of this expansive flooded island.

The two turbidity monitoring stations Holland Cut near Bethel Island and False River near Oakley are continuously affected by the water flowing in and out of Franks Tract throughout the daily tidal cycle. The Holland Cut station is a court-ordered compliance station; and in both 2007 and 2008, several turbidity events exceeded the 12 NTU threshold during the December 25–January 15 compliance periods. Several of these turbidity events were triggered by strong winds that thoroughly mixed exposed bottom sediments in Franks Tract and caused turbidity pulses to move down Holland Cut on a flood tide. Several possible contributing factors to the localized turbidity events were identified in the 2007 Delta Smelt Turbidity Monitoring Project Report. These factors include:

1) Water temperatures during the late fall and early winter are at their lowest and so is the biological activity, which normally provides bottom sediment stability and sediment filtration. With limited biological activity, bed material was allowed to accumulate in Franks Tract and become increasingly exposed and vulnerable to mixing by a high wind event much like the one that took place on December 24–25, 2007.
2) Fall estuary wind and tidal conditions presented a contributory factor to the December 24–25, 2007, wind event since the Delta is typically associated with weak winds and weak tides during the fall, allowing for sediments to settle to the bottom and accumulate.
3) The Delta was experiencing strong tides (solstice), which contribute to greater turbidity levels and allow turbidity levels to persist for longer periods of time.
4) Franks Tract is an expansive, shallow water body with low currents, providing ideal conditions for sediment deposition.
5) Because of its shallow depth, Franks Tract is subject to mixing from wind and wave action.
6) A low tide event combined with the wind-induced waves in Franks Tract thoroughly mixes bottom sediments and provides re-suspension of material.

All six of these factors can be affected by the growth of *Egeria densa* in Franks Tract. This is due to *Egeria densa's* ability to grow in large subsurface mats all over Franks Tract, and act as a filter collecting and allowing organic and inorganic materials to accumulate and settle. This organic and inorganic matter that normally would be transported throughout the Delta is then susceptible to significant mixing due to wind-induced wave action in Franks Tract, which we have witnessed during both compliance periods of 2007–2008 and 2008–2009.

The turbidity monitoring at the Holland Cut near Bethel Island compliance station was established September 2007, and the False River station in December 2007. DBW treatment of *Egeria densa* in 2007 and 2008 occurred from April through July. During the 2007–2008 compliance period, we witnessed much higher daily turbidity average and more severe pulses of turbidity due to wave-action in Franks Tract than we witnessed in 2008–2009. This can be attributed to several factors, including severity of wind/storm events, tidal cycle, and precipitation runoff. Another factor could be the increased efforts in the treatment of *Egeria densa* in 2007 and 2008 in Franks Tract prior to the 2008–2009 compliance period. In 2006, DBW had treated only a

140-acre portion of site 173; but in both 2007 and 2008, a total of 2,570 acres were treated in all three site locations: 173, 174, and 175. Widespread treatment reduced bio-volume and bio-cover in 2007 and 2008 setting up for the lowest bio-mass in *Egeria densa* in several years in Franks Tract for the 2008–2009 compliance period. The low levels of *Egeria densa* in Franks Tract should reduce the capabilities of Franks Tract to accumulate excessive organic and inorganic materials that could be suddenly re-suspended by wind-induced wave action. This phenomenon could explain the lower turbidity levels recorded from both Holland Cut near Bethel Island and False River stations during the 2008–2009 compliance period.

Operational Changes and the Effects on Combined Old and Middle River Negative Flows

An important factor in the overall hydrodynamics in the Delta is the net negative flows in Old and Middle Rivers (OMR). This phenomenon is produced by the water diversions at both the SWP and CVP. These net negative flows have effects on both the water quality and the biological community of the entire tidal estuary system. Specifically, these net negative flows have been linked to increased entrainment of threatened and endangered pelagic fish species such as the longfin smelt and delta smelt (Grimaldo et al. 2009). Significant operational changes to reduce these negative flows during predicted delta smelt-spawning migration were implemented with the release of the 2005 USFWS OCAP Biological Opinion. Further actions were taken with the Wanger Decision (which found the 2005 OCAP Biological Opinion unlawful and inadequate for the protection of the threatened species delta smelt) and resulted in the development of the 2008 USFWS OCAP Biological Opinion, which established new specific OMR limits and several triggers that would cause a change in exports at both facilities during the 2008 and following winter-spring delta smelt migration months of December–June.

In 2008, due to Wanger decisions, water diversions and operations were changed to protect winter-spring delta smelt during their migration period. DSWG held meetings to analyze current real-time delta smelt abundance and distribution data and to recommend to USFWS operations that would provide the best protection from entrainment at the SWP and CVP export facilities. These recommendations were then relayed to the Water Operations and Management Team (WOMT) for implementation. The 2008 actions implemented:

1) A 10-day winter pulse OMR flow that was triggered by turbidity. This ensured that OMR flows were no more negative than 2,000 cfs.
2) After the 10-day winter pulse flow, a net daily upstream OMR flow was maintained not to exceed 5,000 cfs over a 7-day running average.
3) The OMR net daily upstream flow was then limited to a flow of 750 to 5,000 cfs determined by weekly meetings between USFWS, DWR, and USBR through June 20. This resulted in an OMR flow between -2,000 and -3,000 cfs maintained by SWP and CVP.
4) SWP and CVP implemented the Vernalis Adaptive Management Plan from April 22 through May 22, with San Joaquin River flows of 3,000 cfs. The Old River at Head barrier was not installed.

The preceding actions were all implemented based on the current conditions provided to the DSWG through the use of the established DSRAM framework for guidance (http://www.fws.gov/sacramento/es/documents/SWP-CVP_OPs_BO_12-15_final_OCR.pdf).

Historical flow data from 2000 to 2003 and 2005 to 2008 provided by the USGS stations Middle River at Middle River (MDM) and Old River at Bacon Island (OBI) were analyzed (data were acquired from multiple years to represent annual variation in water-year type) to better understand the effects on OMR flow dynamics and delta smelt salvage numbers due to the implementation of the 2005 and 2008 OCAP Biological Opinions.

> “Combined Old and Middle River daily net flows (non-tidally averaged) were used instead of actual SWP and CVP water diversions to determine entrainment effects because these daily net flows reasonably measure the hydrodynamic ‘pull’ of the exports.” (*from* Grimaldo et al. 2009)

Flow data were used from December through June due to predicted timing of adult delta smelt pre-spawn migration (Bennett 2005) and because the historical salvage data indicating the highest delta smelt entrainment occurs during this time period.

The OMR combined flow data during December through June from all the years analyzed maintained a predominant reverse direction except for the December 2005 to June 2006 delta smelt entrainment period (Figure 17 and Figure 18). This was the only entrainment period that was analyzed that occurred during an above normal to wet year. There was also a subsequent reduction in delta smelt salvage at both SWP and CVP during that same time period. There was a noticeable decline in the reverse mean flow during the subsequent years after 2003, which was noted as one of the highest salvage years of delta smelt (Figure 19).

The 2007–2008 continuous turbidity data from HOL and OBI were also compared with OMR flow to try to capture a delta smelt salvage response with the first winter turbidity pulse flow event down Old River during the December 2007–June 2008 delta smelt entrainment period. (Data was used from the OBI station to eliminate a possible localized turbidity event occurring in Franks Tract due to a wind event.) Graphically we see a strong relationship between increased delta smelt salvage with turbidity values above 12 NTU (Figure 20). Turbidity values began to rise above 12 NTU after January 4, and the first salvaged adult delta smelt appeared at the CVP on January 11 and SWP on January 17. This turbidity pulse event continued to escalate through February, and we continued to see increased numbers of salvaged delta smelt at both facilities. OMR flows during the months of January through February maintained a 60-day running average flow of -3979 cfs with a maximum negative flow of -7003 cfs and a minimum of -294 cfs. We see a second turbidity pulse in late May into June and once again see an increase in delta smelt salvage despite the reduction in OMR negative flows during this period.

Summary and Discussion

In 2008, NCRO successfully improved the network of turbidity stations within the Delta with the establishment of four new continuous turbidity stations. This development completes the first priority stations that were recommended in 2007. These telemetered continuous water quality stations include Sacramento River near Verona (VON), Mokelumne River near Highway 12 (MOK), Three Mile Slough at San Joaquin River (TSL), and San Joaquin River at Jersey Point (JER). The additional stations will provide further information on turbidity movement throughout the interior Delta, and pave the way toward an early warning system that will help SWP and CVP operators to more efficiently manage project exports to minimize negative impacts to delta smelt.

The average turbidity levels were much higher during the 2007–2008 compliance period than in 2008–2009. On December 25, 2007, at 4:15 PST, turbidity levels at Holland Cut near Bethel Island (HOL) triggered the restriction of pumping at both the state and federal pumping facilities for 10 days. The HOL station averaged over 12 NTU for the entire 2007–2008 compliance period. All three stations averaged higher turbidity levels and a higher number of readings over the 12 NTU threshold than during the 2008–2009 compliance period. Several factors can be attributed to the higher turbidity levels that were observed in 2007–2008, but the most noticeable was the presence of two strong storms that occurred on December 25, 2007, and January 4, 2008. Both storms resulted in sustained strong winds and on January 4 brought significant rainfall to the Central Valley. Another possible factor that caused a reduction in turbidity levels in 2008–2009 was the decreased presence of the invasive aquatic plant *Egeria densa* in Franks Tract, which can grow in large subsurface mats that capture and store sediments moving throughout the Delta. These accumulated sediments can then be susceptible to re-suspension from strong winds much like the ones that occurred on December 25, 2007, and January 4, 2008.

During the 2008–2009 compliance period, only one significant wind event in the Delta affected the turbidity data at the HOL compliance station. Compared with wind speeds recorded in 2007, this wind event on December 25, 2008, was much less severe. Therefore, with a maximum wind speed of 15 mph at 12:00 PST, there was only a short window of high turbidity readings at the HOL station that occurred during the flood tide. The tide changed around 9:30 PST and began incoming until about 18:30 PST, bringing wind-induced turbidity created in Franks Tract down Holland Cut. Wind speeds increased around 9:15 PST and sustained average wind speeds of 11.20 mph during the entire incoming tide. This resulted in the HOL station recording all 17 of its readings over 12 NTU for the 2008–2009 compliance period. Utilizing turbidity data collected at the False River Near Oakley (FAL) and Old River near Bacon Island at USGS (OBI) water quality stations during the same time period revealed that those elevated turbidity readings recorded at HOL were due to a localized wind event. The turbidity levels at OBI during the entire incoming tide on December 25, 2008, never rose above 6.1 NTU; therefore, turbidity levels over 12 NTU were not moving past HOL and down toward the Skinner Delta Fish Protective and Tracy Fish Collection salvage facilities. The FAL station, as expected, recorded increased turbidity levels on the ebb-tide as water pulled out of Franks Tract and through False River after the sustained high winds on December 25.

Due to the localized wind-induced turbidity events created in Franks Tract during both the 2007–2008 and 2008–2009 compliance periods, we investigated the removal of the invasive plant *Egeria densa* in Franks Tract during 2006, 2007, and 2008. The significance of *Egeria densa* is within its life history traits and specifically its ability to filter out suspended organic and inorganic particles in the water column. Data from DBW on individual site treatment acreage within Franks Tract during 2006, 2007, and 2008 exposed significant improvements in treatment effort and reduction success of *Egeria densa* during each succeeding year. Therefore, with an increase in the reduction of *Egeria densa* from 2006–2008, we should see in time a decline in its ability to filter and collect suspended organic and inorganic material. These phenomena could explain the low turbidity levels recorded in the 2008–2009 compliance period, which occurred after the two strong treatment years of 2007 and 2008. The low treatment of *Egeria densa* and the continuous settling of suspended sediments in Franks Tract over the years prior to the 2007–2008 compliance period could have been a key factor in the number of turbidity readings above 12 NTU after the heavy wind events re-suspended collected filtered sediments within the *Egeria densa* mats.

Another important factor in the water quality within the Delta is flow. Flow within the central Delta is strongly influenced by the SWP and CVP water exports. Significant changes were adopted with the 2008 Wanger Decision to reduce the negative flows within OMR during the key delta smelt migration periods, in an effort to reduce entrainment. Historical data from 2000–2003 showed much greater reverse flows and much higher numbers of delta smelt salvage. Most of these years were dry and critical years. With the development of the 2005 and, more importantly, the 2008 OCAP Biological Opinion, we saw a considerable decrease in negative flow and a decrease in smelt salvage at both facilities.

Utilizing continuous turbidity data from HOL and OBI in 2007–2008, we monitored the first pulses of turbidity greater than 12 NTU moving down Old River in January and February while a significant increase in delta smelt salvage was reported. OMR was maintaining a predominately reverse flow direction during this time period, though delta smelt salvage did not occur until turbidity surpassed 12 NTU at both stations. This helps demonstrate the importance that spring turbidity pulses may play on triggering delta smelt spawning migration and movement into the central Delta. It also reinforces the importance of having a 12 NTU-turbidity trigger at the three compliance stations, which currently allow water operators the ability to implement a 10-day OMR winter pulse flow in an effort to reduce any potential increases in SWP and CVP delta smelt salvage.

Project Recommendations

With the addition of new monitoring stations, we are developing a new understanding of turbidity movement in the Delta. Through the continuous turbidity data we have collected at our stations, we have documented the potential local and widespread effects of Franks Tract on the development and movement of turbidity through Old River. We should look closer into our study of Franks Tract and continue analyzing turbidity, wind, tidal conditions, and USGS onsite flow data in this highly dynamic junction in the Delta on an annual basis. We should also make an effort to look at biological factors such as *Egeria densa*, which has spread prolifically throughout the Delta and has known effects on turbidity and flow, especially in low current and shallow areas.

There are still many locations throughout the Delta where we need to increase monitoring of temperature, specific conductance, and turbidity. Through several meetings with staff from DWR, DFG, USGS, USBR, the State Water Contractors, and DSWG, a comprehensive priority list for establishing new water quality station locations has been established.

Second Priority:

1) Cache Slough at Ryer Island
2) Middle River at Middle River
3) Sacramento Ship Channel
4) San Joaquin River at Bradford Island
5) Lisbon Slough in Yolo Bypass
6) Sacramento River at Emmaton

Third Priority:

7) Napa River at Mare Island
8) Suisun/Grizzly Bay
9) Honker Bay
10) Suisun Gates

These 10 stations will provide DWR and other agencies with more temperature, specific conductance, and turbidity data from critical areas in the Delta. This network of stations will lead to a more comprehensive data set that yields a better understanding of the relationship between changing water quality conditions and delta smelt migration. A more complete understanding of these relationships will allow the SWP and CVP operators to more efficiently operate within the Delta to minimize negative impacts to the delta smelt while also meeting project exports.

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Table 3. Statistical summary of 2008 continuous water temperature, specific conductance, and turbidity data: Victoria Canal, Holland Cut, Old River, and False River

Month	Water temperature (ºC)			
Maximums	Victoria Canal	Holland Cut	Old River	False River
Jan	9.22	8.67	8.79	8.45
Feb	13.31	12.71	12.8	12.89
Mar	16.71	16.43	16.22	15.13
Apr	20.35	19.17	19.48	18.73
May	24.42	24.04	24.08	21.45
Jun	25.89	25.77	25.17	23.59
Jul	26.87	25.51	25.94	24.37
Aug	26.48	26.02	25.44	23.93
Sep	25.05	25.45	24.75	23.85
Oct	22.80	21.80	22.29	20.80
Nov	17.31	17.18	17.28	17.07
Dec	13.42	13.37	13.40	12.37
Averages	Victoria Canal	Holland Cut	Old River	False River
Jan	8.03	7.73	7.80	7.84
Feb	9.94	9.71	9.50	9.61
Mar	14.31	13.87	14.10	13.44
Apr	16.70	16.28	16.63	15.76
May	19.92	19.53	20.07	18.75
Jun	22.50	21.87	22.26	20.68
Jul	24.80	23.36	23.80	22.15
Aug	24.93	23.83	24.10	22.50
Sep	22.96	21.82	22.05	21.04
Oct	18.46	17.12	18.05	17.87
Nov	15.32	15.06	15.16	14.71
Dec	9.67	9.57	9.67	9.26

Month	Specific conductance (µS/cm)			
Maximums	Victoria Canal	Holland Cut	Old River	False River
Jan	750.4	1029	862.2	3638
Feb	586.9	405.4	414.3	359.1
Mar	546.50	345.60	418.90	331.30
Apr	551.90	368.00	462.90	424.00
May	535.40	383.00	481.50	533.50
Jun	474.30	353.00	365.10	878.40
Jul	372.50	605.00	493.20	2231.40
Aug	439.20	952.00	765.40	2968.90
Sep	504.30	1146.00	942.80	3748.70
Oct	475.00	840.70	662.40	3965.40
Nov	521.50	1053.90	873.70	4536.70
Dec	635.20	1080.60	891.70	6100.60
Averages	Victoria Canal	Holland Cut	Old River	False River
Jan	527.70	579.50	602.84	603.37
Feb	427.28	323.71	333.89	289.96
Mar	449.62	310.68	341.66	286.04
Apr	498.45	319.64	362.81	305.79
May	490.11	332.87	394.64	312.75
Jun	393.65	304.48	332.26	353.77
Jul	287.14	411.77	384.10	685.45
Aug	346.60	708.95	646.20	1198.15
Sep	430.56	831.11	778.12	1233.75
Oct	443.67	620.75	576.19	1117.99
Nov	443.57	772.63	700.05	1457.51
Dec	554.37	859.98	788.04	1481.66

Month	Turbidity (NTU)			
Maximums	Victoria Canal	Holland Cut	Old River	False River
Jan	27.75	44.4	30.8	87.7
Feb	32.89	364.9	117.5	90
Mar	18.79	123.50	39.40	44.90
Apr	16.11	57.60	25.80	20.60
May	17.10	121.70	42.00	62.90
Jun	15.30	70.60	46.10	32.10
Jul	24.30	36.50	53.40	43.00
Aug	17.00	65.00	19.40	19.40
Sep	16.00	37.00	21.50	18.90
Oct	12.00	75.10	17.00	17.60
Nov	7.20	6.80	10.30	14.80
Dec	8.60	21.90	10.50	23.00
Averages	Victoria Canal	Holland Cut	Old River	False River
Jan	10.18	16.54	14.80	30.73
Feb	16.77	38.80	29.50	40.50
Mar	9.31	22.86	20.78	19.71
Apr	6.59	14.15	11.93	10.86
May	7.26	21.59	14.81	14.58
Jun	8.54	21.66	18.77	20.52
Jul	9.77	14.38	14.47	16.52
Aug	5.73	7.57	8.25	9.63
Sep	4.05	5.48	6.56	8.17
Oct	2.43	7.25	5.14	7.72
Nov	2.23	3.40	3.42	6.33
Dec	2.84	4.08	3.45	7.08

Table 3 (cont'd). Statistical summary of 2008 …

Month	Water temperature (ºC)			
Minimums	Victoria Canal	Holland Cut	Old River	False River
Jan	6.94	6.78	6.71	7.22
Feb	7.73	7.31	7.36	7.58
Mar	11.94	11.29	11.91	11.45
Apr	14.48	14.00	14.89	14.03
May	17.33	16.33	17.25	16.32
Jun	19.11	18.90	19.73	18.59
Jul	23.19	20.59	22.05	20.54
Aug	23.68	21.53	22.66	21.40
Sep	20.96	18.95	19.66	18.89
Oct	15.67	13.24	14.73	15.41
Nov	13.43	13.29	13.39	12.20
Dec	7.48	7.29	7.50	6.79
Std Devs.	Victoria Canal	Holland Cut	Old River	False River
Jan	0.42	0.40	0.40	0.28
Feb	1.25	1.34	1.31	1.24
Mar	1.11	1.27	1.18	0.93
Apr	1.32	1.11	1.05	0.98
May	1.71	1.77	1.64	1.25
Jun	1.87	1.44	1.53	1.18
Jul	0.75	0.94	0.74	0.74
Aug	0.60	0.89	0.69	0.51
Sep	1.11	1.46	1.34	1.26
Oct	2.02	2.31	1.94	1.51
Nov	0.94	0.94	0.95	1.37
Dec	1.91	1.94	1.95	1.47
2008-Max.	26.87	26.02	25.94	24.37
2008-Avg.	17.31	16.66	16.97	16.17
2008-Min.	6.94	6.78	6.71	6.79
2008-S.D.	5.89	5.57	5.62	5.12

Month	Specific conductance (µS/cm)			
Minimums	Victoria Canal	Holland Cut	Old River	False River
Jan	438.3	371.4	384.6	302.8
Feb	360.4	270	293.2	256.7
Mar	372.20	287.40	299.80	248.10
Apr	450.40	299.00	315.50	274.60
May	407.30	292.00	328.00	278.40
Jun	319.50	273.30	307.40	239.60
Jul	247.40	271.10	272.00	243.50
Aug	280.40	491.60	464.40	642.60
Sep	374.80	602.70	618.30	564.70
Oct	414.50	505.60	507.10	515.20
Nov	417.70	601.70	600.50	405.80
Dec	490.00	711.90	689.30	677.10
Std Devs.	Victoria Canal	Holland Cut	Old River	False River
Jan	34.84	170.78	150.72	339.68
Feb	39.44	28.46	31.96	13.38
Mar	34.47	8.59	30.42	11.71
Apr	17.52	10.15	36.50	18.04
May	27.67	13.74	35.84	27.89
Jun	34.85	17.50	11.38	80.61
Jul	17.39	95.56	80.72	336.00
Aug	36.77	88.98	77.44	442.47
Sep	39.45	111.18	84.42	497.49
Oct	10.36	58.93	40.34	516.19
Nov	17.20	102.35	75.93	609.31
Dec	31.56	60.62	40.02	730.50
2008-Max.	750.40	1146.00	942.80	6100.60
2008-Avg.	441.11	532.21	523.01	780.45
2008-Min.	247.40	270.00	272.00	239.60
2008-S.D.	77.94	226.61	185.57	608.11

Month	Turbidity (NTU)			
Minimums	Victoria Canal	Holland Cut	Old River	False River
Jan	3.24	4.7	7.9	7.7
Feb	9.55	16.3	14.4	19.2
Mar	4.50	6.30	7.20	8.30
Apr	2.97	5.40	7.20	6.40
May	3.80	7.80	7.00	7.60
Jun	4.40	12.10	10.10	12.80
Jul	4.30	6.80	6.90	7.80
Aug	1.90	3.20	3.80	5.20
Sep	1.50	2.30	2.10	4.20
Oct	0.40	2.10	1.70	3.60
Nov	0.80	1.70	1.40	2.90
Dec	1.50	1.90	1.40	3.00
Std Devs..	Victoria Canal	Holland Cut	Old River	False River
Jan	4.07	5.64	3.96	11.48
Feb	2.89	31.97	14.47	9.75
Mar	2.61	12.29	7.25	6.17
Apr	1.89	6.35	3.00	2.04
May	1.54	15.75	5.19	4.94
Jun	1.65	7.54	5.14	2.90
Jul	2.94	4.29	4.83	4.08
Aug	2.05	2.53	2.21	1.59
Sep	1.58	1.84	2.18	1.57
Oct	1.11	8.13	2.05	2.03
Nov	0.88	0.66	0.89	1.78
Dec	0.83	1.70	0.71	2.52
2008-Max.	32.89	364.90	117.50	90.00
2008-Avg.	7.10	15.02	12.53	15.88
2008-Min.	0.40	1.70	1.40	2.90
2008-S.D.	4.53	15.32	9.46	11.24

Table 4. Statistical summary of 2008 continuous water temperature, specific conductance, and turbidity data: Verona, Three Mile Slough, Mokelumne River, and Jersey Point

Month	Water temperature (ºC)			
Maximums	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	12.20	-	-	-
Mar	17.20	-	-	-
Apr	20.40	17.64	18.04	-
May	25.60	21.64	23.08	-
Jun	25.20	22.21	24.27	-
Jul	25.80	23.13	25.38	23.11
Aug	25.70	23.86	24.33	24.03
Sep	24.30	23.42	22.94	24.14
Oct	21.60	21.05	21.76	21.20
Nov	15.80	17.06	16.99	17.04
Dec	12.60	13.79	13.08	13.61
Averages	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	10.56	-	-	-
Mar	13.92	-	-	-
Apr	16.41	16.21	16.33	-
May	20.10	18.76	19.57	-
Jun	22.36	20.00	21.65	-
Jul	23.33	21.81	23.11	21.98
Aug	23.50	22.47	22.83	22.46
Sep	21.45	21.09	21.44	21.01
Oct	16.98	17.85	17.99	17.85
Nov	13.71	15.14	14.66	15.52
Dec	9.18	10.14	9.54	10.03

Month	Specific conductance (µS/cm)			
Maximums	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	-	-	-	-
Mar	-	-	-	-
Apr	128.00	336.00	279.70	-
May	159.00	395.00	309.30	-
Jun	173.00	626.41	271.09	-
Jul	153.00	1500.88	259.09	2872.40
Aug	159.00	1968.70	323.00	3807.50
Sep	212.00	2634.80	371.50	4548.80
Oct	144.00	3445.00	302.30	5368.70
Nov	245.00	3893.20	454.91	5750.30
Dec	207.00	4984.30	648.69	7319.00
Averages	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	-	-	-	-
Mar	-	-	-	-
Apr	115.81	271.29	201.59	-
May	130.63	281.14	220.37	-
Jun	115.97	302.69	174.91	-
Jul	128.65	550.99	162.58	981.73
Aug	127.81	955.49	192.85	1476.75
Sep	152.20	954.85	201.12	1503.95
Oct	129.67	1063.52	167.87	1440.38
Nov	192.82	1218.72	220.97	1789.86
Dec	184.42	1335.73	251.25	1830.31

Month	Turbidity (NTU)			
Maximums	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	-	-	-	-
Mar	42.00	-	-	-
Apr	49.00	18.40	24.10	-
May	19.00	33.80	37.20	-
Jun	33.00	35.20	43.10	-
Jul	17.00	34.40	22.10	27.60
Aug	9.80	21.70	15.50	27.10
Sep	9.70	31.00	19.80	20.60
Oct	9.90	27.70	27.70	22.80
Nov	13.00	24.50	13.60	27.00
Dec	42.00	22.40	41.00	28.30
Averages	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	-	-	-	-
Mar	19.09	-	-	-
Apr	16.93	11.09	6.76	-
May	10.92	16.72	11.27	-
Jun	12.39	21.77	11.66	-
Jul	8.00	18.13	7.06	13.44
Aug	5.75	13.07	5.64	9.81
Sep	6.43	12.80	4.72	8.06
Oct	6.25	11.19	2.64	8.63
Nov	7.53	8.64	3.80	7.29
Dec	14.53	9.03	4.48	7.78

Table 4 (cont'd). Statistical summary of 2008 …

Month	Water temperature (ºC)			
Minimums	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	9.40	-	-	-
Mar	11.50	-	-	-
Apr	13.70	14.60	14.17	-
May	16.40	16.66	16.62	-
Jun	19.70	17.56	18.65	-
Jul	20.90	19.69	21.31	20.69
Aug	21.40	21.13	21.44	21.27
Sep	19.20	18.98	20.00	18.90
Oct	13.10	16.07	15.77	15.71
Nov	11.60	13.53	12.41	13.28
Dec	7.00	7.74	7.25	7.78
Std. Devs.	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	0.75	-	-	-
Mar	1.40	-	-	-
Apr	1.64	0.63	0.88	-
May	2.30	1.23	1.55	-
Jun	1.34	1.13	1.25	-
Jul	1.16	0.75	0.91	0.47
Aug	1.08	0.55	0.57	0.54
Sep	1.30	1.23	0.62	1.26
Oct	2.00	1.54	1.79	1.47
Nov	1.15	0.80	0.96	0.74
Dec	1.47	1.92	1.73	1.76
2008-Max.	25.80	23.86	25.38	24.14
2008 -Avg.	17.96	18.24	18.60	19.30
2008-Min.	7.00	7.74	7.25	7.78
2008-S.D.	4.90	3.92	4.42	2.91

Month	Specific conductance (µS/cm)			
Minimums	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	-	-	-	-
Mar	-	-	-	-
Apr	106.00	217.50	134.10	-
May	108.00	221.30	139.90	-
Jun	93.00	201.00	130.00	-
Jul	111.00	235.50	143.20	529.00
Aug	116.00	494.80	162.00	750.50
Sep	121.00	526.41	159.70	684.09
Oct	117.00	484.30	145.70	597.50
Nov	138.00	404.09	163.30	464.70
Dec	163.00	440.00	204.30	735.00
Std. Devs.	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	-	-	-	-
Mar	-	-	-	-
Apr	6.01	24.99	34.27	-
May	12.75	21.31	35.32	-
Jun	21.26	42.65	36.38	-
Jul	11.52	200.17	16.33	456.80
Aug	10.16	237.06	27.57	652.68
Sep	23.33	283.11	27.60	694.94
Oct	7.27	493.27	21.31	781.73
Nov	28.33	474.08	40.04	858.49
Dec	9.43	690.47	52.58	1052.44
2008-Max.	245.00	4984.30	648.69	7319.00
2008-Avg.	142.93	789.02	199.22	1548.69
2008-Min.	93.00	201.00	130.00	464.70
2008-S.D.	31.26	532.92	43.51	827.94

Month	Turbidity (NTU)			
Minimums	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	-	-	-	-
Mar	7.00	-	-	-
Apr	3.90	5.20	3.50	-
May	5.80	7.30	4.40	-
Jun	4.00	13.90	5.10	-
Jul	3.80	11.50	2.60	9.00
Aug	2.60	7.40	2.30	5.70
Sep	2.80	5.50	1.90	4.00
Oct	3.50	4.20	1.40	4.30
Nov	5.00	3.70	1.80	3.40
Dec	4.40	3.20	1.60	3.30
Std. Devs.	Verona	Three Mile	Mokelumne	Jersey
Jan	-	-	-	-
Feb	-	-	-	-
Mar	13.16	-	-	-
Apr	4.35	1.88	2.26	-
May	6.63	3.81	4.33	-
Jun	3.19	3.26	5.01	-
Jul	1.94	2.89	1.99	2.06
Aug	2.04	2.50	1.52	2.15
Sep	1.98	3.54	1.50	2.13
Oct	2.58	3.48	1.25	2.44
Nov	9.75	2.87	1.06	2.21
Dec	9.38	3.17	2.25	2.81
2008-Max.	49.00	35.20	43.10	28.30
2008-Avg.	10.72	13.74	6.46	8.78
2008-Min.	2.60	3.20	1.40	3.30
2008-S.D.	8.23	5.30	4.03	2.92

Table 5. Statistical summary of 2008 continuous water temperature, specific conductance, and turbidity data: Prisoners Point

Month	Water temperature (ºC)	Month	Specific conductance (µS/cm)	Month	Turbidity (NTU)
Maximums	Prisoners Point	Maximums	Prisoners Point	Maximums	Prisoners Point
Jan	8.17	Jan	400	Jan	39.3
Feb	12.06	Feb	380	Feb	45
Mar	15.50	Mar	364	Mar	26
Apr	18.11	Apr	365	Apr	13
May	22.83	May	379	May	36.5
Jun	24.22	Jun	300	Jun	36.1
Jul	25.06	Jul	297	Jul	16.1
Aug	25.06	Aug	447	Aug	9.9
Sep	25.00	Sep	501	Sep	-
Oct	22.06	Oct	367	Oct	-
Nov	17.17	Nov	556	Nov	7.9
Dec	13.56	Dec	591	Dec	15.2
Averages		Averages		Averages	
Jan	8.06	Jan	345	Jan	22.49
Feb	9.59	Feb	292	Feb	22.52
Mar	13.66	Mar	312	Mar	8.65
Apr	16.05	Apr	322	Apr	4.60
May	19.21	May	324	May	8.73
Jun	21.30	Jun	252	Jun	11.97
Jul	23.05	Jul	229	Jul	5.38
Aug	23.61	Aug	340	Aug	4.49
Sep	21.65	Sep	360	Sep	-
Oct	18.13	Oct	316	Oct	-
Nov	15.14	Nov	399	Nov	3.07
Dec	9.94	Dec	476	Dec	4.48

Table 5 (cont'd). Statistical summary of 2008 …

Month	Water temperature (ºC)	Month	Specific conductance (µS/cm)	Month	Turbidity (NTU)
Minimums		Minimums		Minimums	
Jan	7.89	Jan	260	Jan	19.7
Feb	7.56	Feb	243	Feb	9
Mar	11.50	Mar	268	Mar	1.9
Apr	14.33	Apr	279	Apr	1.8
May	16.89	May	262	May	3.6
Jun	18.78	Jun	194	Jun	6
Jul	21.28	Jul	193	Jul	2.5
Aug	22.17	Aug	261	Aug	2.8
Sep	15.28	Sep	254	Sep	-
Oct	16.11	Oct	273	Oct	-
Nov	13.44	Nov	285	Nov	0.3
Dec	7.61	Dec	379	Dec	0.3
Std. Devs.		Std. Devs.		Std. Devs.	
Jan	0.09	Jan	30	Jan	4.71
Feb	1.24	Feb	20	Feb	7.15
Mar	1.03	Mar	16	Mar	3.63
Apr	0.86	Apr	18	Apr	1.30
May	1.26	May	24	May	4.72
Jun	1.31	Jun	27	Jun	3.93
Jul	0.73	Jul	24	Jul	1.62
Aug	0.55	Aug	29	Aug	1.17
Sep	1.43	Sep	40	Sep	-
Oct	1.72	Oct	16	Oct	-
Nov	0.84	Nov	68	Nov	1.53
Dec	1.92	Dec	36	Dec	2.29
2008-Max.	25.06	2008-Max.	591.00	2008-Max.	45.00
2008-Avg.	17.23	2008-Avg.	358.53	2008-Avg.	7.63
2008-Min.	7.56	2008-Min.	193.00	2008-Min.	0.30
2008-S.D.	4.92	2008-S.D.	76.03	2008-S.D.	6.38

Figure 2. Water temperature data (15-minute intervals), 2008: Victoria Canal, Holland Cut, Old River, and False River

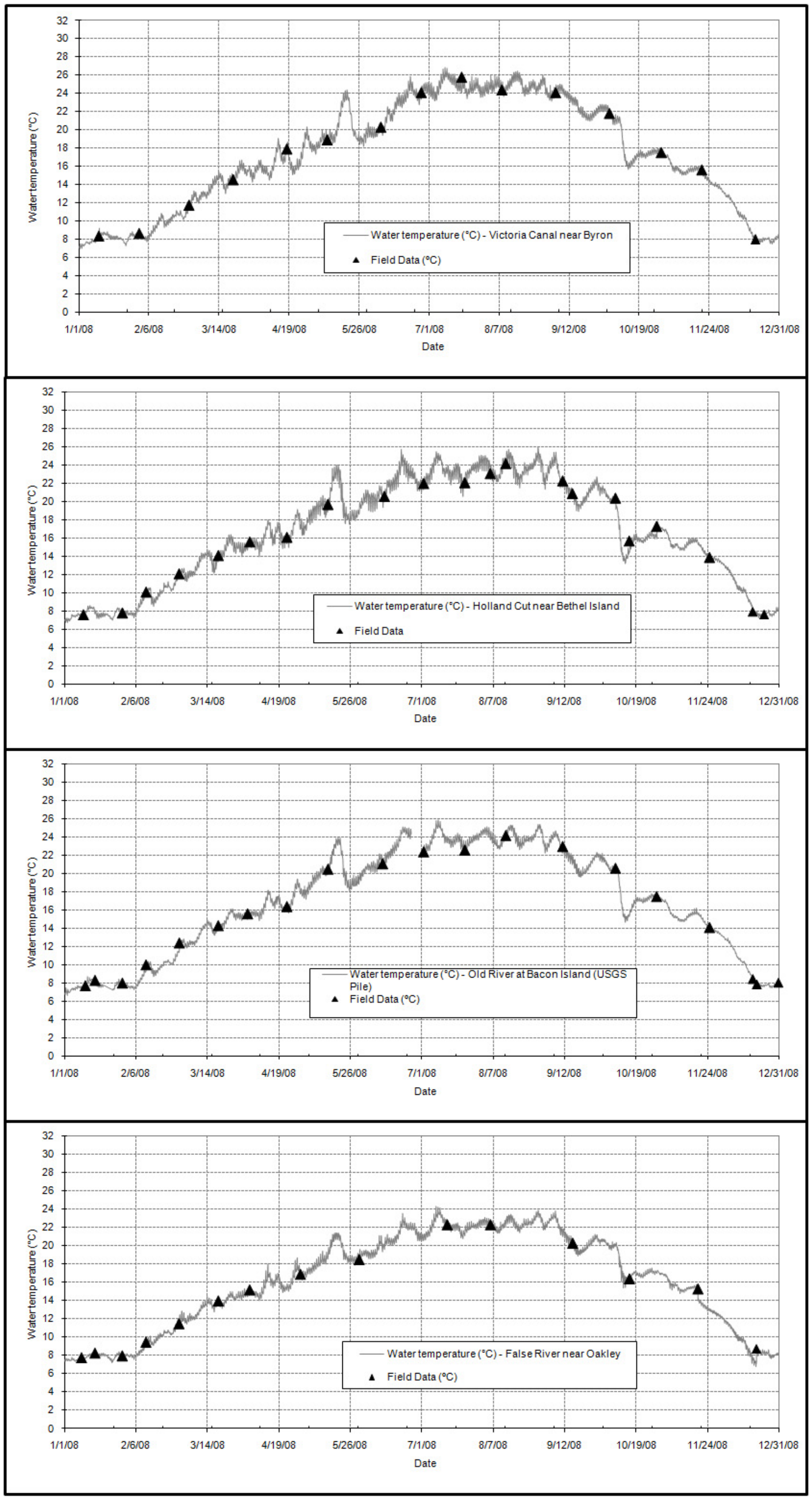

Figure 3. Water temperature data (15-minute intervals), 2008: Mokelumne River, Three Mile Slough, Jersey Point, and Prisoners Point

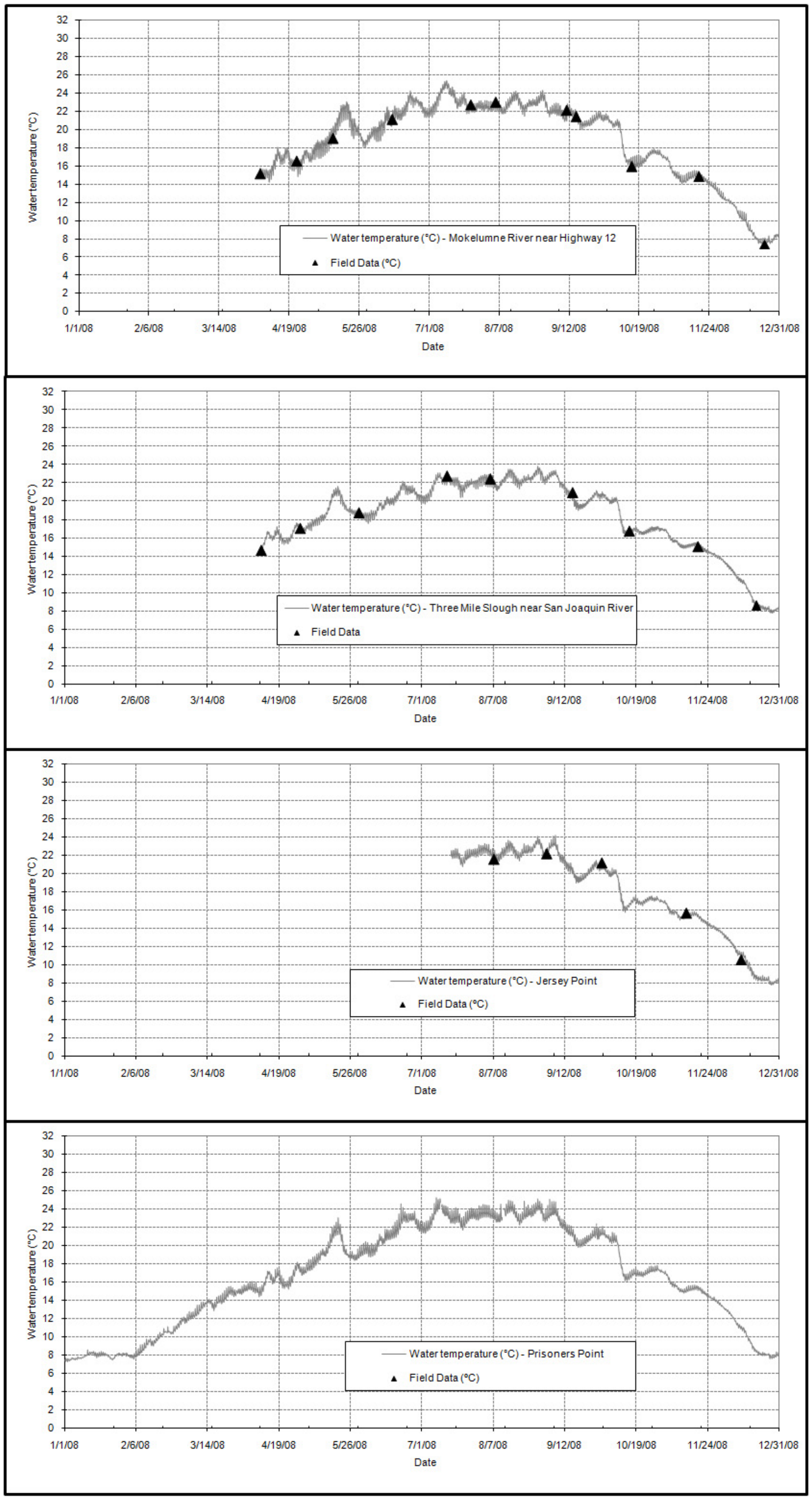

Figure 4. Specific conductance data (15-minute intervals), 2008: Victoria Canal, Holland Cut, Old River, and False River

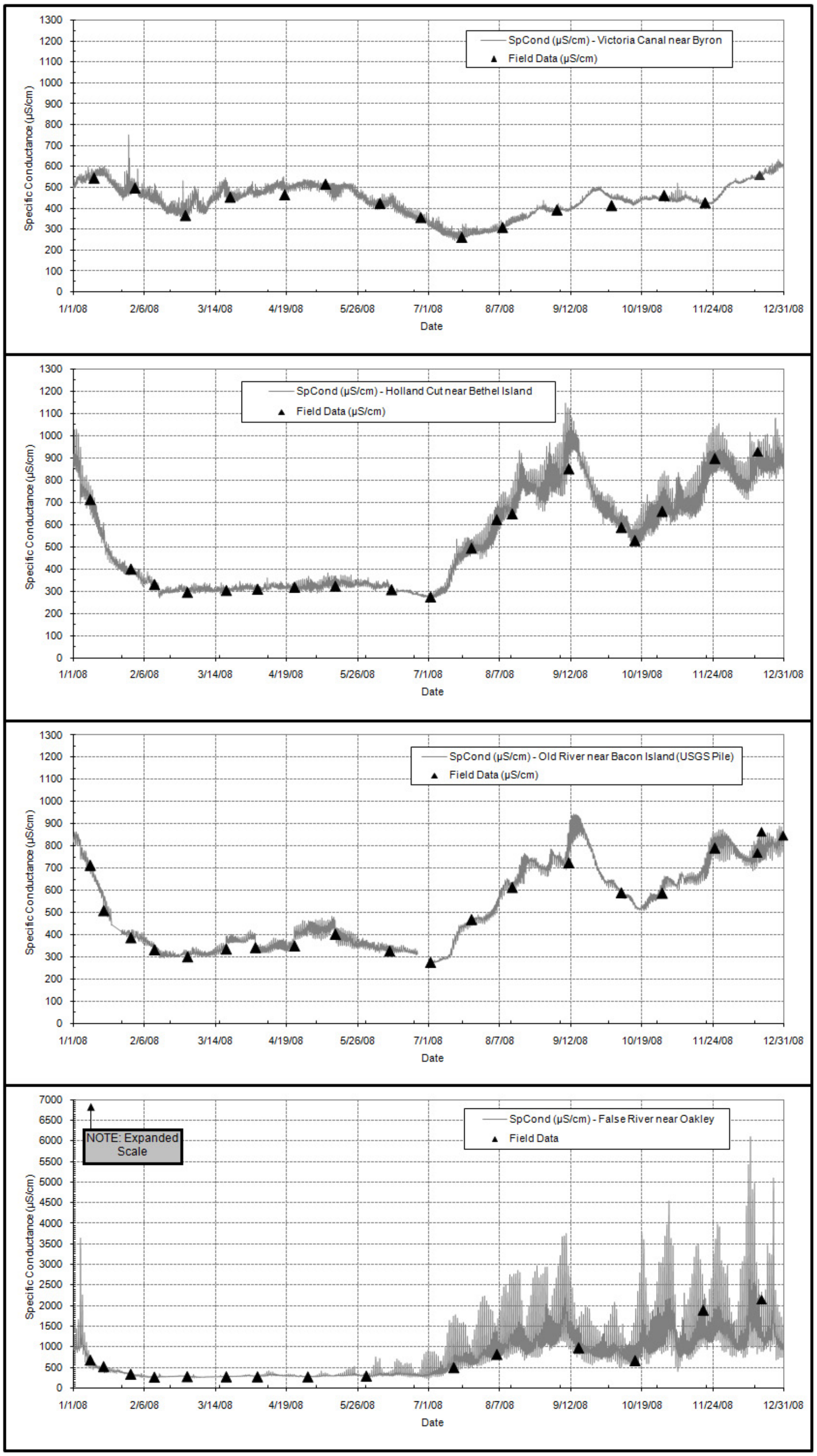

Figure 5. Specific conductance data (15-minute intervals), 2008: Mokelumne River, Three Mile Slough, Jersey Point, and Prisoners Point

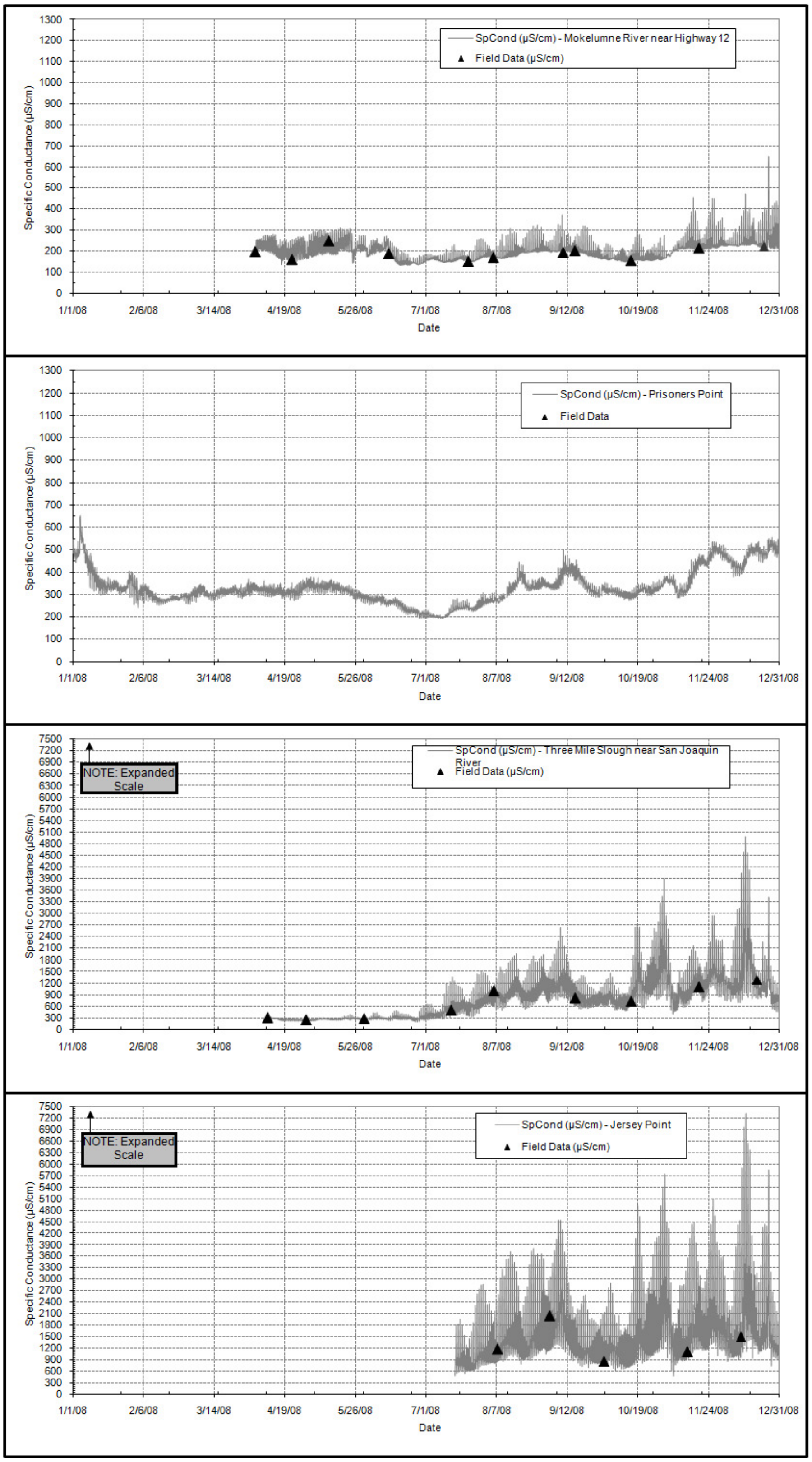

Figure 6. Turbidity data (15-minute intervals), 2008: Victoria Canal, Holland Cut, Old River, and False River

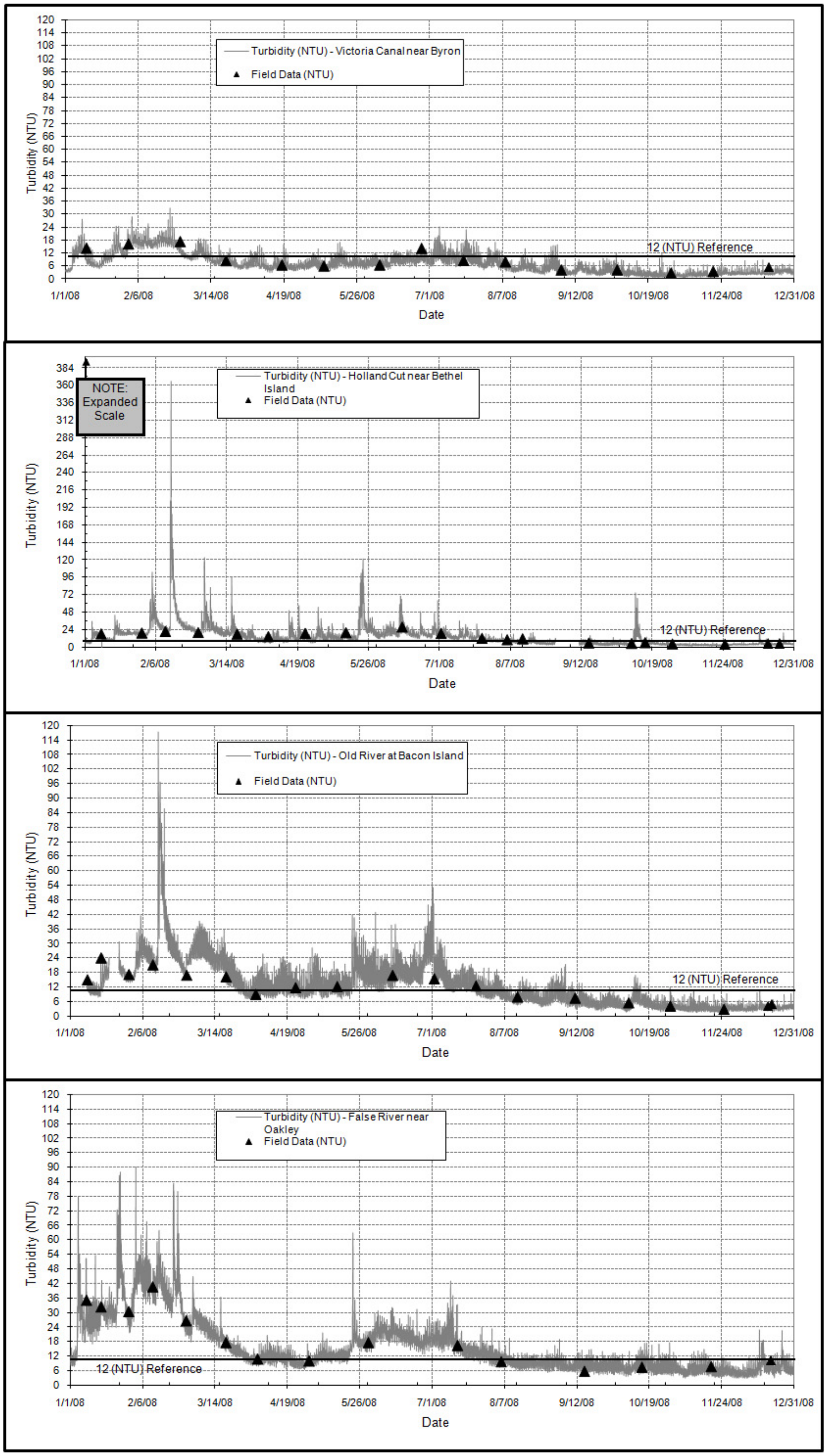

Figure 7. Turbidity data (15-minute intervals), 2008: Mokelumne River, Three Mile Slough, Jersey Point, and Prisoners Point

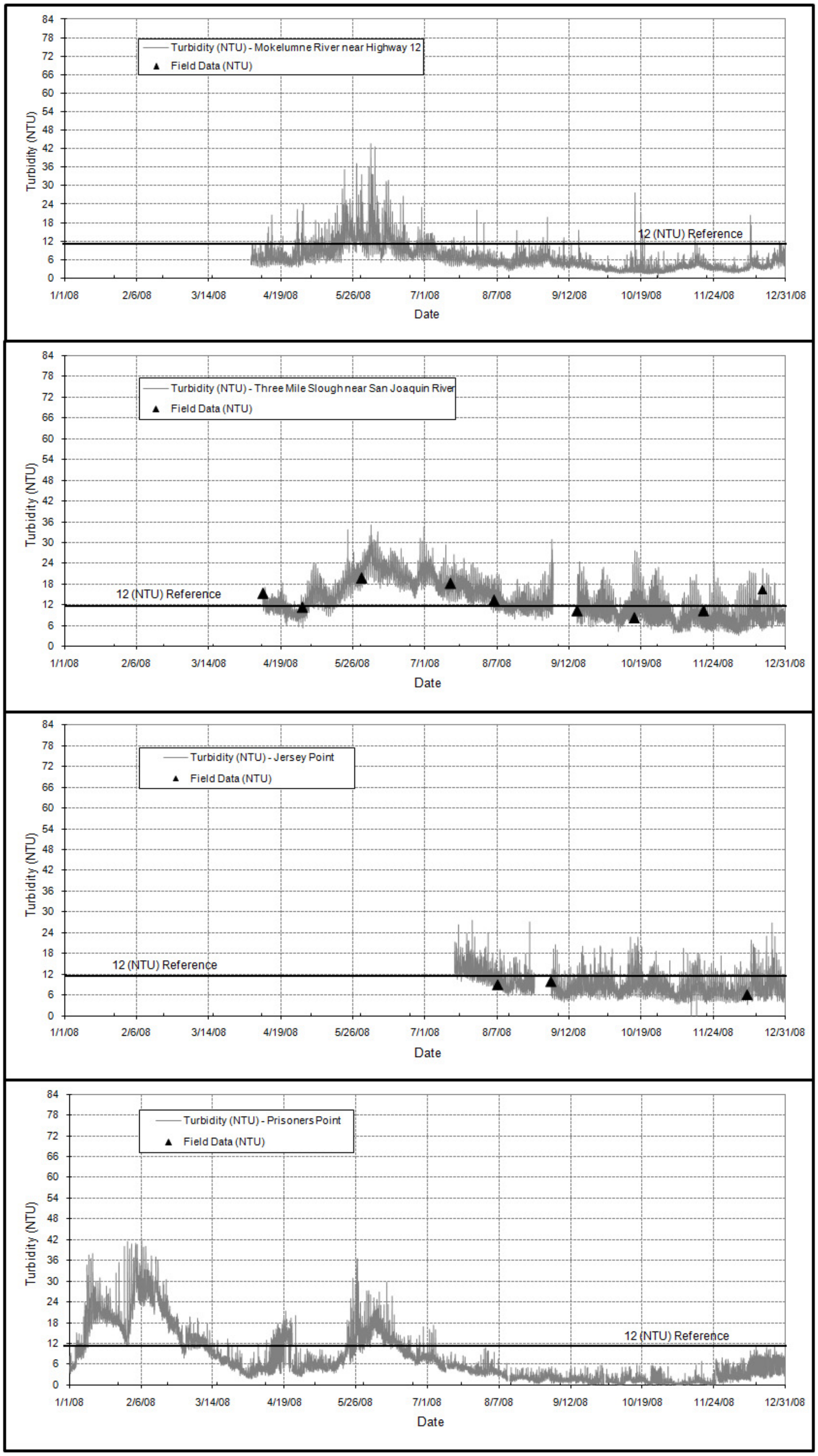

Figure 8. Turbidity data (15-minute intervals), 2007–2008 compliance period: Victoria Canal, Holland Cut, and Prisoners Point

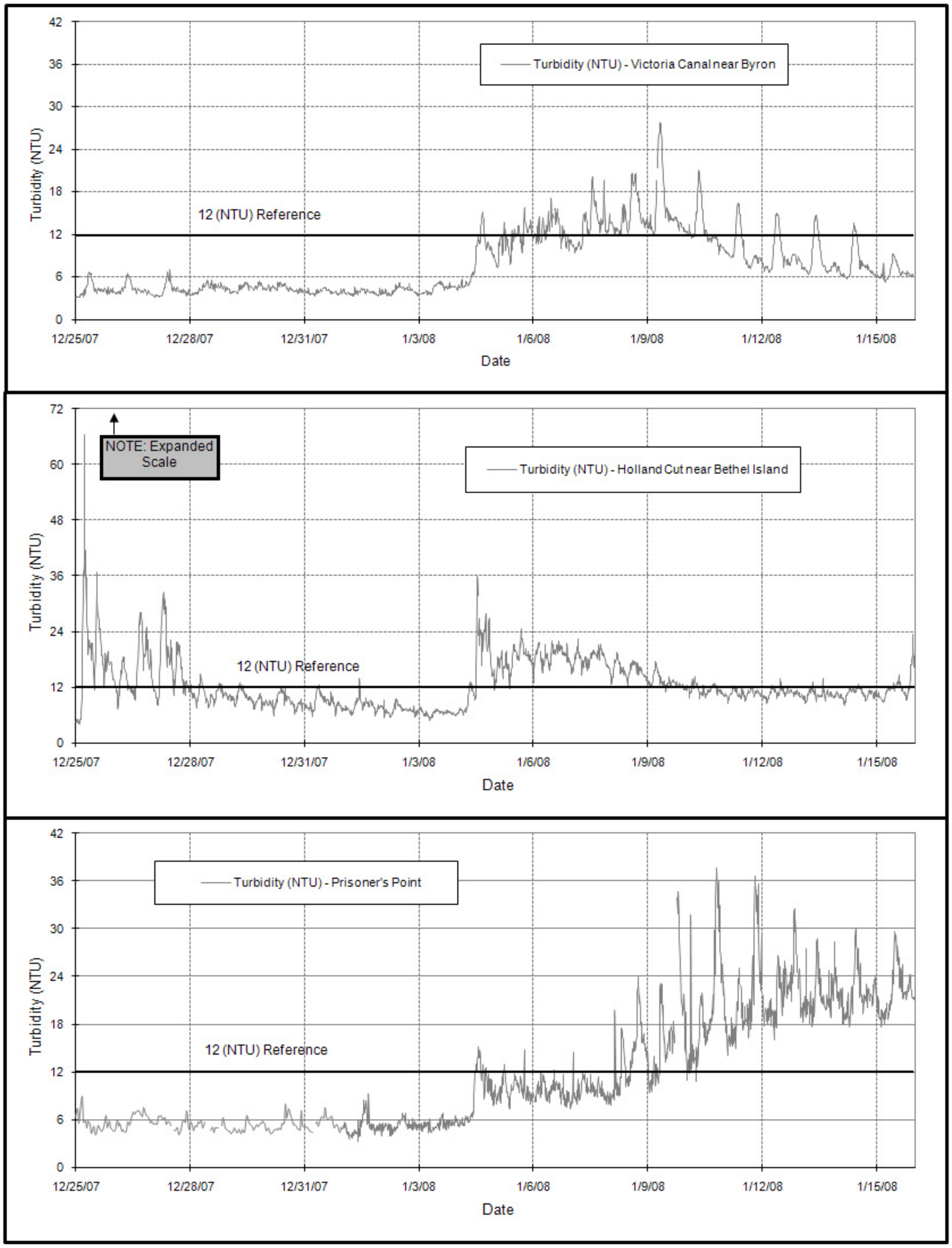

Figure 9. Turbidity readings greater than or equal to 12 NTU (15-minute intervals), 2007–2008 compliance period: Victoria Canal, Holland Cut, and Prisoners Point

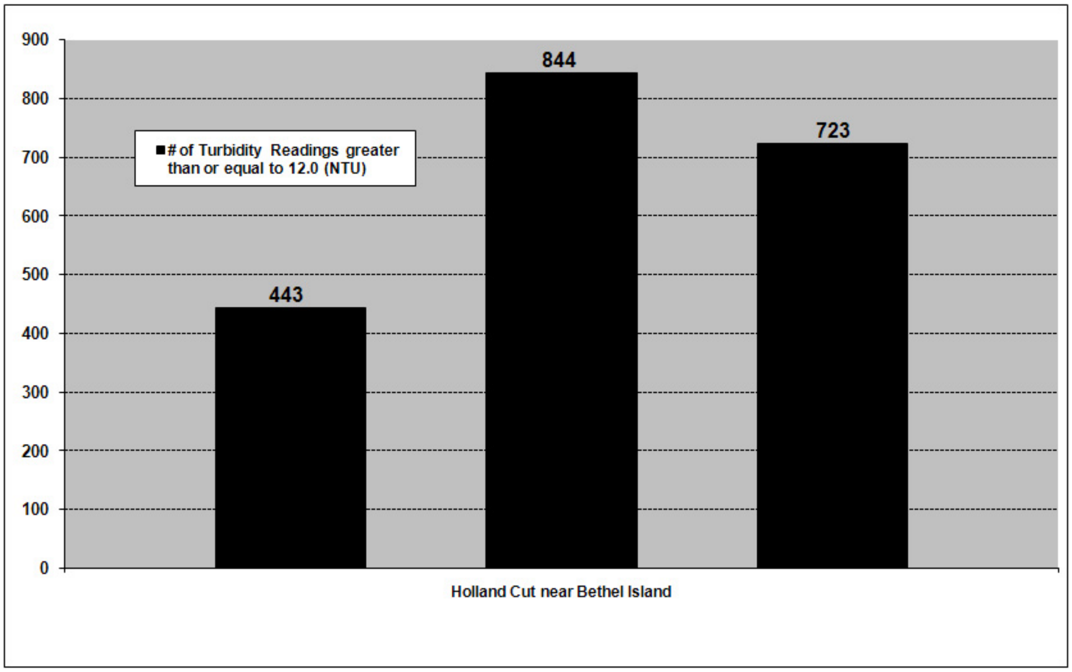

Figure 10. Turbidity data (15-minute intervals), 2008–2009 compliance period: Victoria Canal, Holland Cut, and Prisoners Point

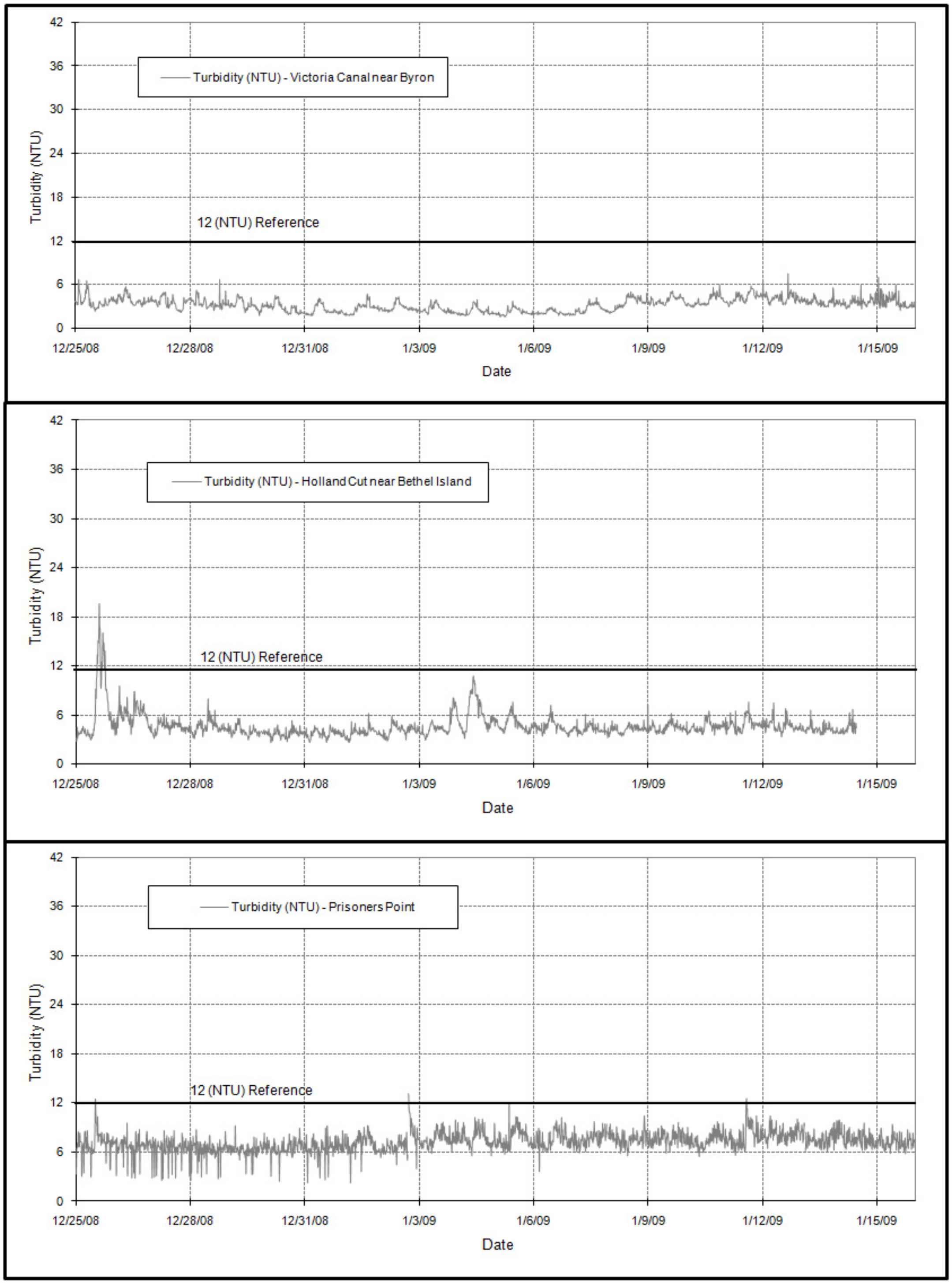

Figure 11. Turbidity readings greater than or equal to 12 NTU (15-minute intervals), 2008–2009 compliance period: Victoria Canal, Holland Cut, and Prisoners Point

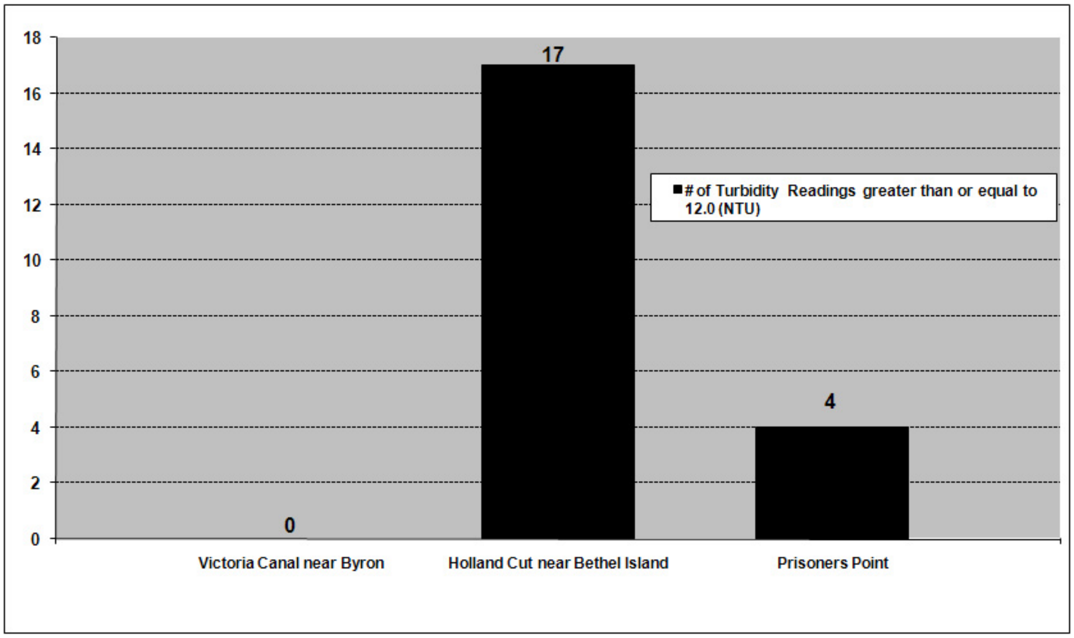

Figure 12. Holland Cut flow, turbidity, and Antioch wind speed data, 2008–2009 compliance period

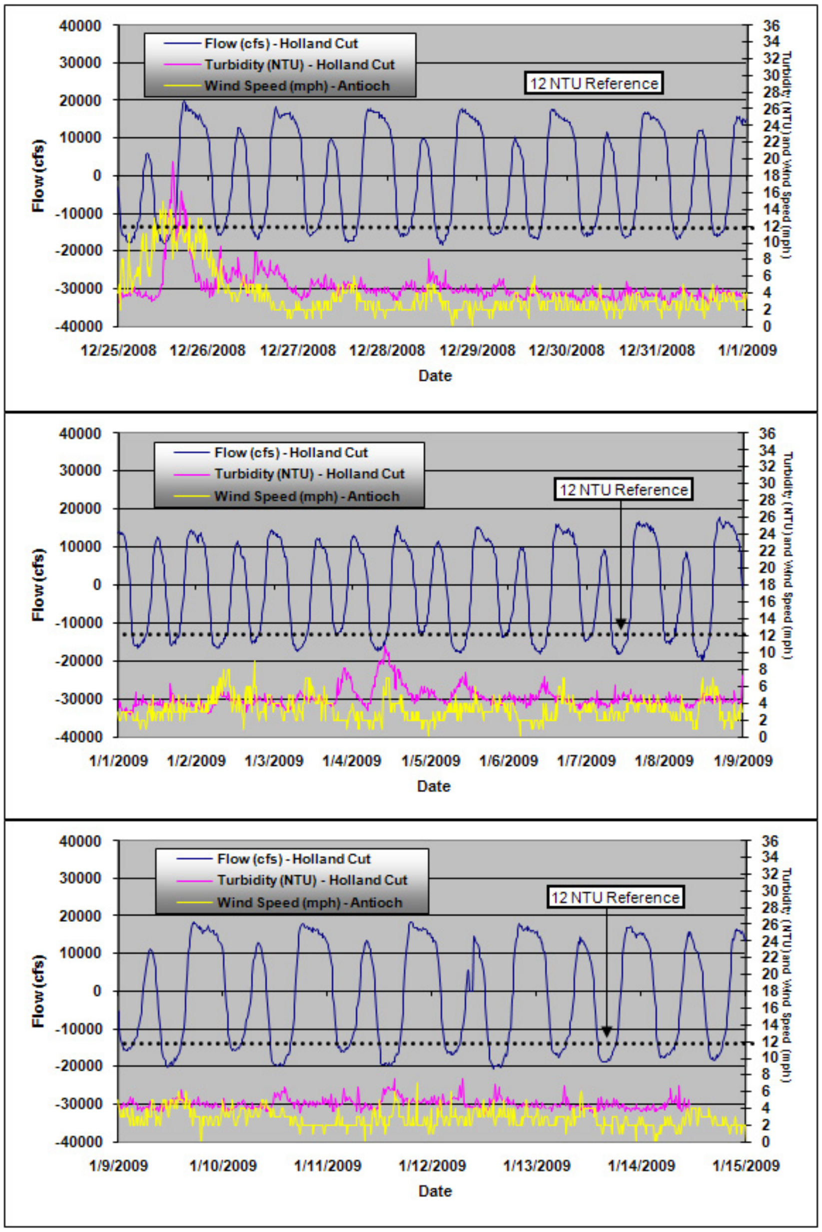

Figure 13. Holland Cut turbidity and flow and Antioch wind speed data, Dec. 25–31, 2008

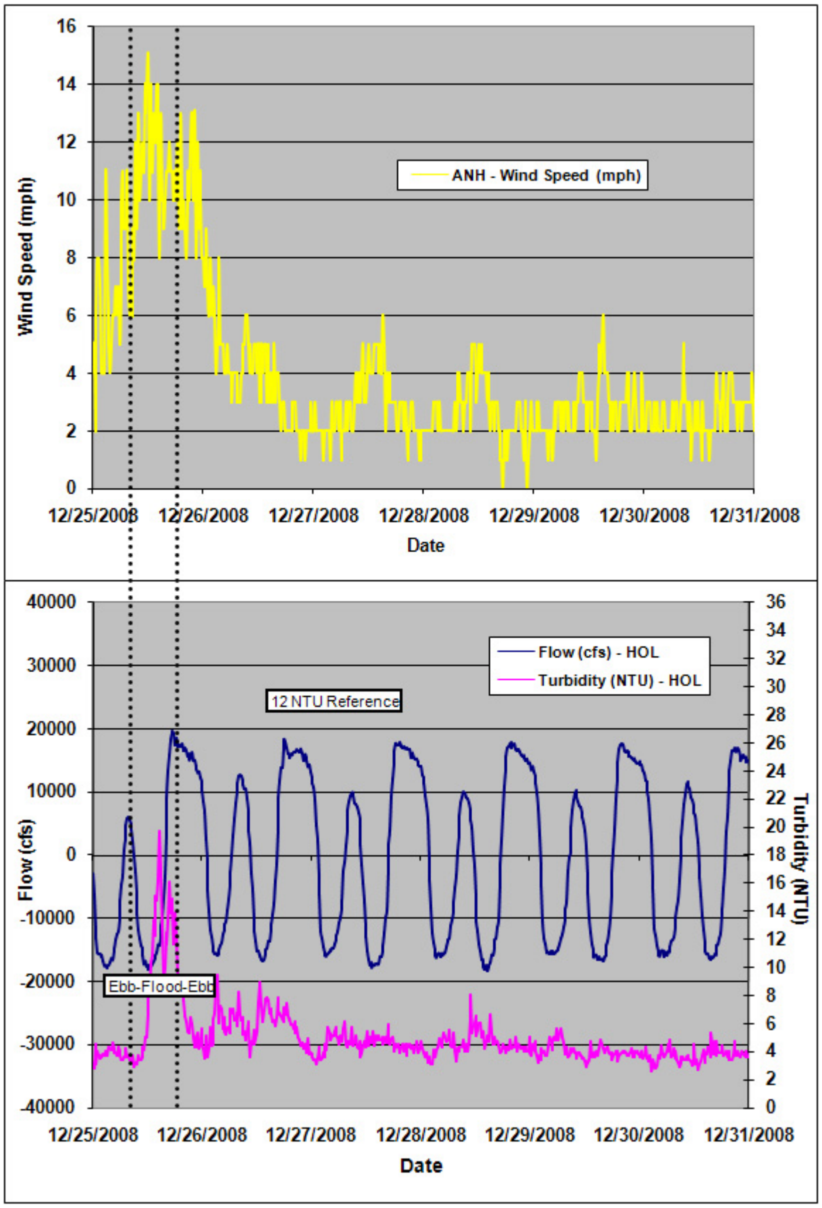

Figure 14. Old River turbidity and flow and Antioch wind speed data, Dec. 25–31, 2008

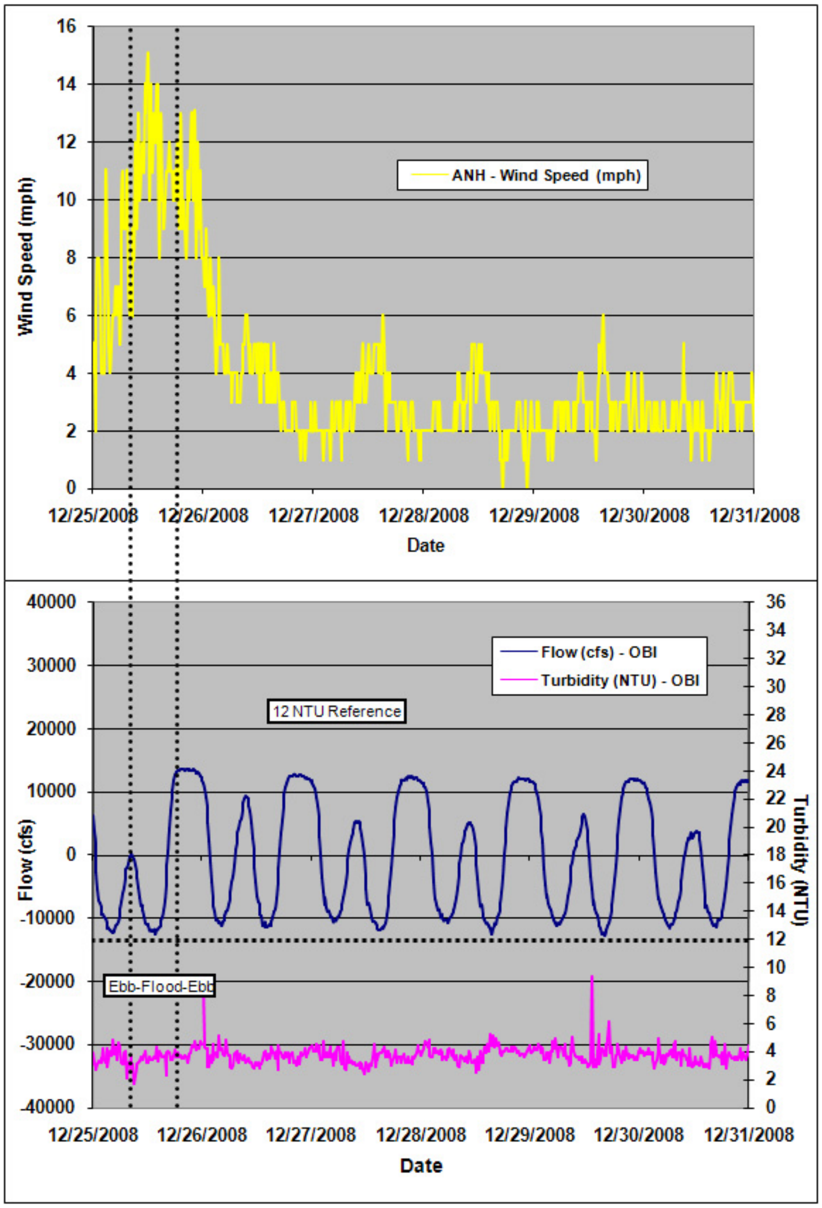

Figure 15. False River turbidity and flow and Antioch wind speed data, Dec. 25–31, 2008

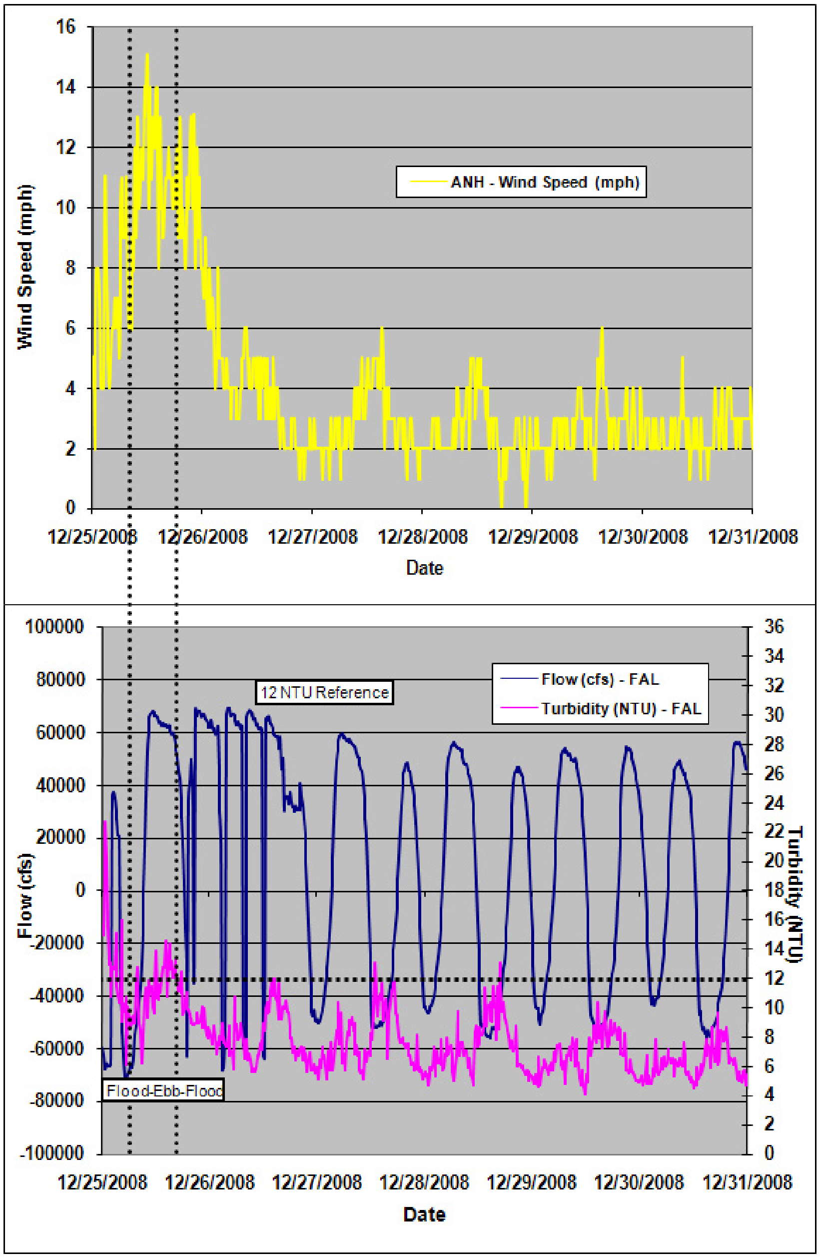

Figure 16. Department of Boating and Waterways *Egeria Densa* treatment sites in Franks Tract

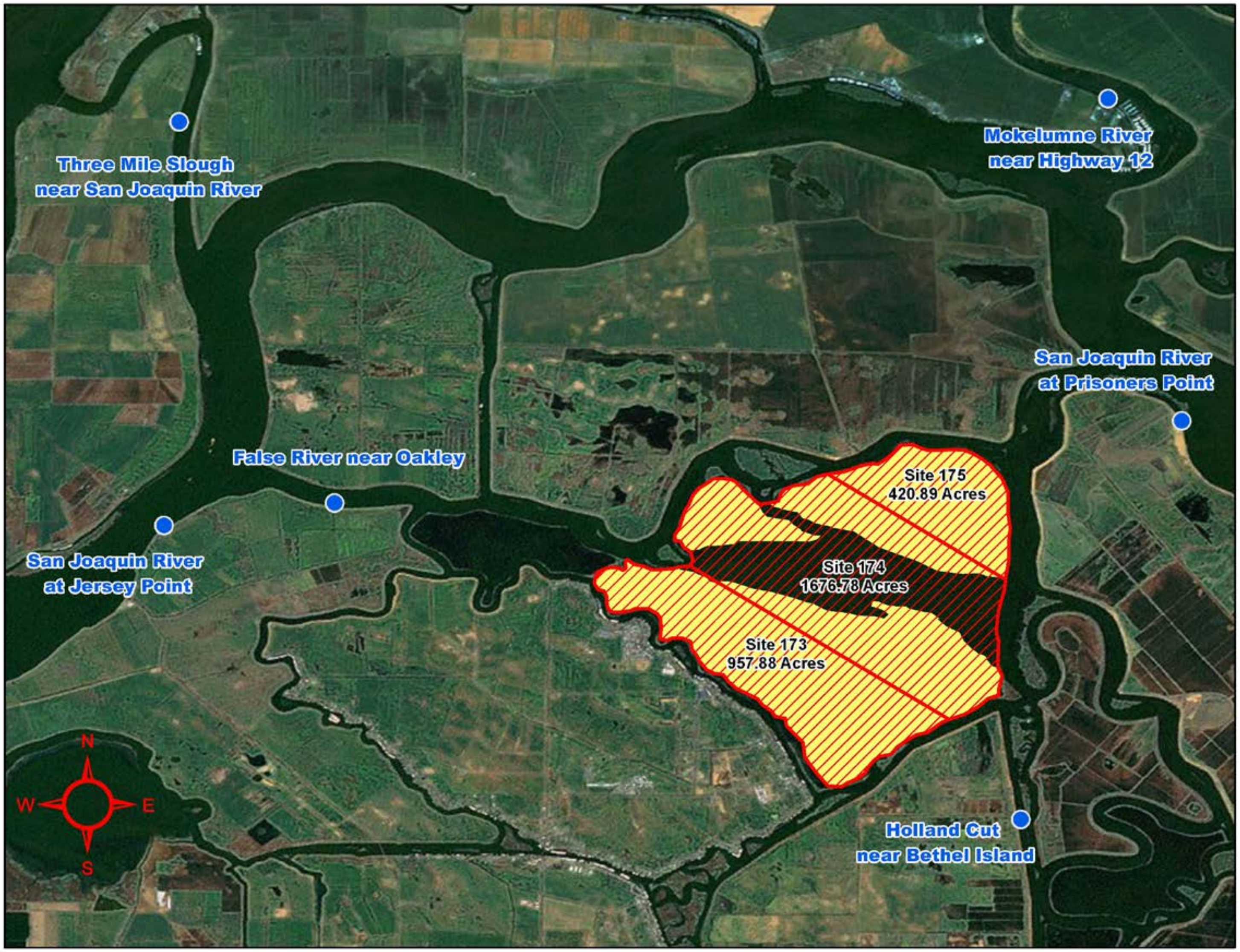

Figure 17. Old and Middle Rivers daily net flows (cfs) and SWP/CVP salvage during Dec-June delta smelt entrainment periods, 2000–2003

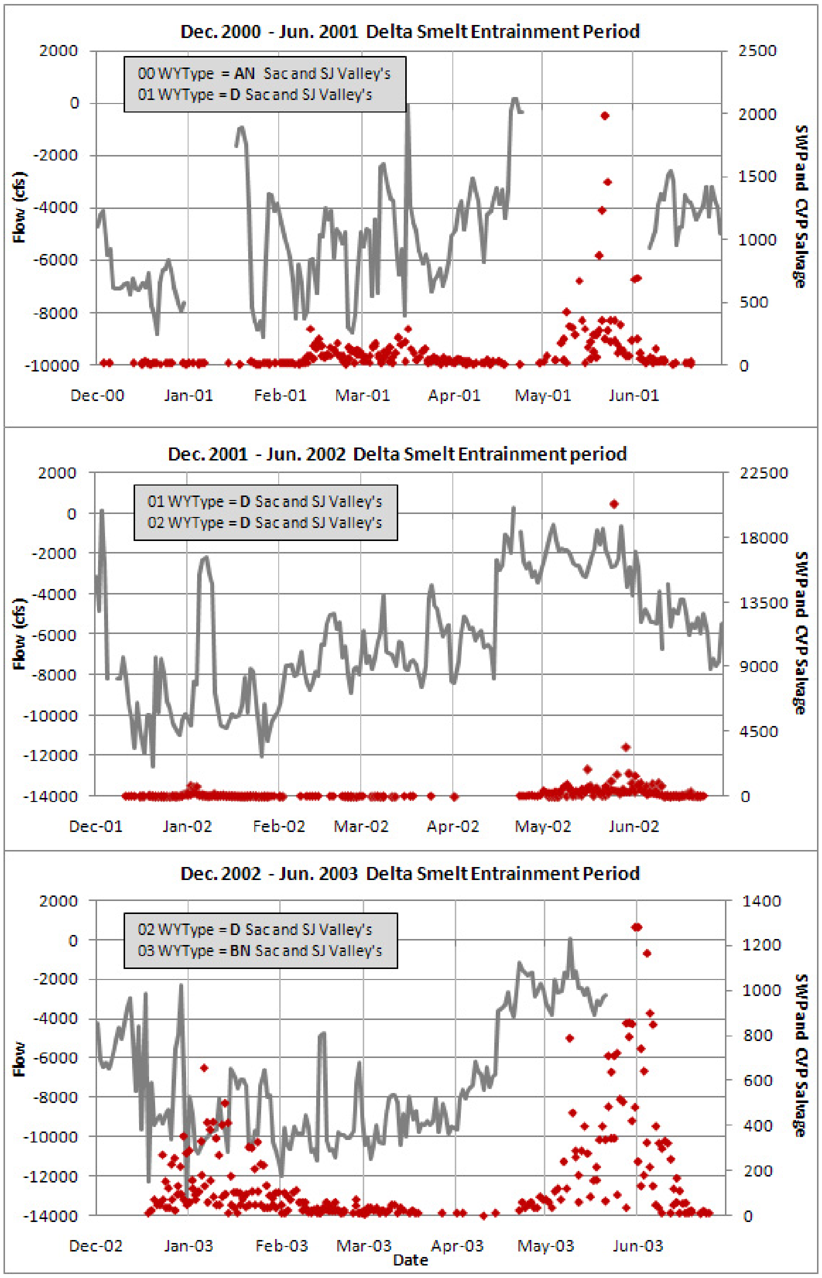

Figure 18. Old and Middle Rivers daily net flows (cfs) and SWP/CVP salvage during Dec-June delta smelt entrainment periods, 2005–2008

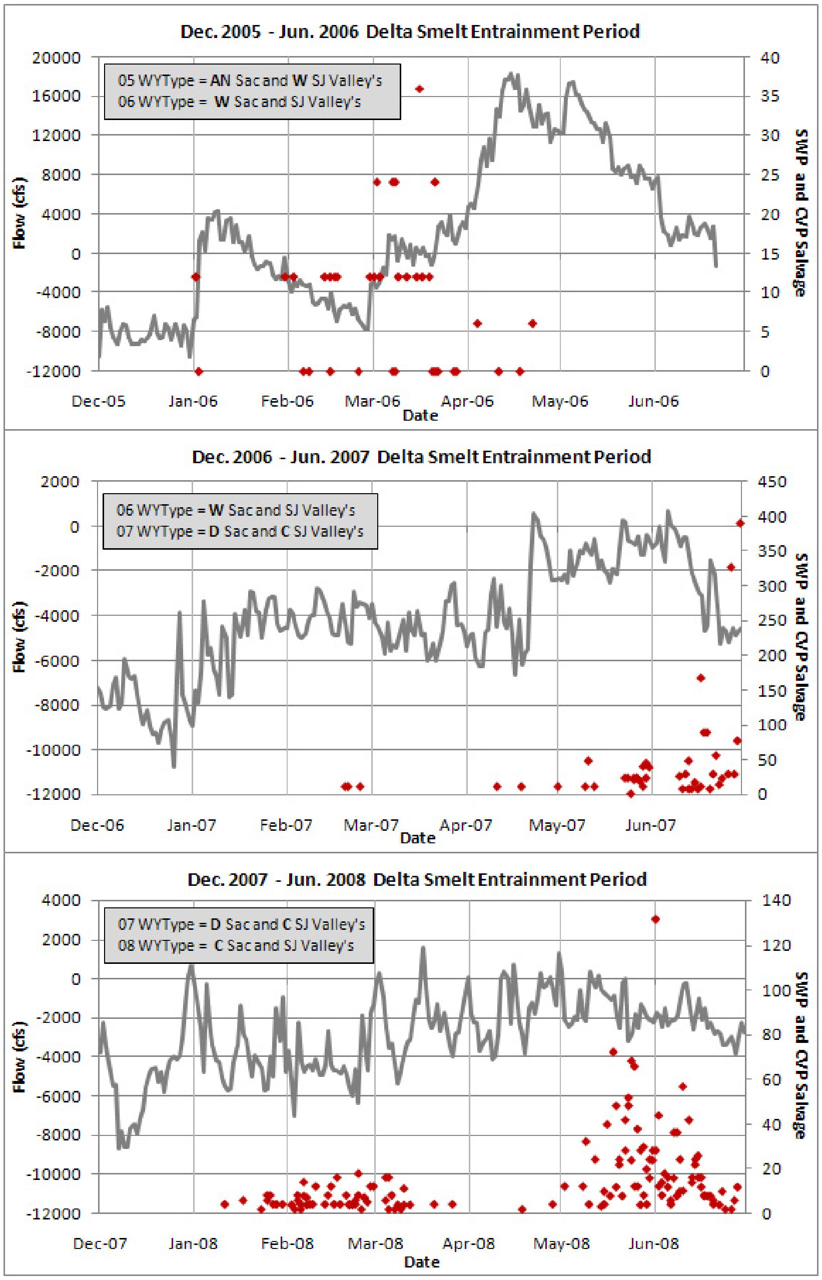

Figure 19. Old and Middle Rivers mean flows (cfs) during Dec-June delta smelt entrainment periods, 2000–2008

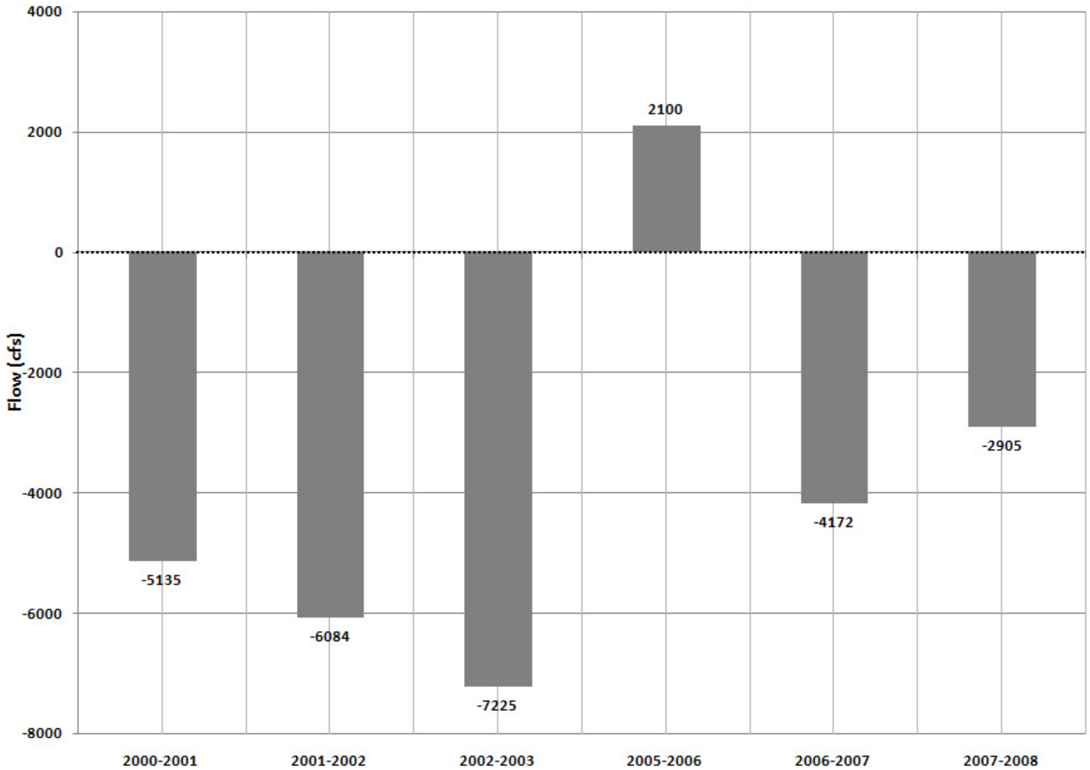

Figure 20. Old and Middle Rivers daily net flow, HOL and OBI turbidity, and delta smelt SWP and CVP salvage, 2007–2008

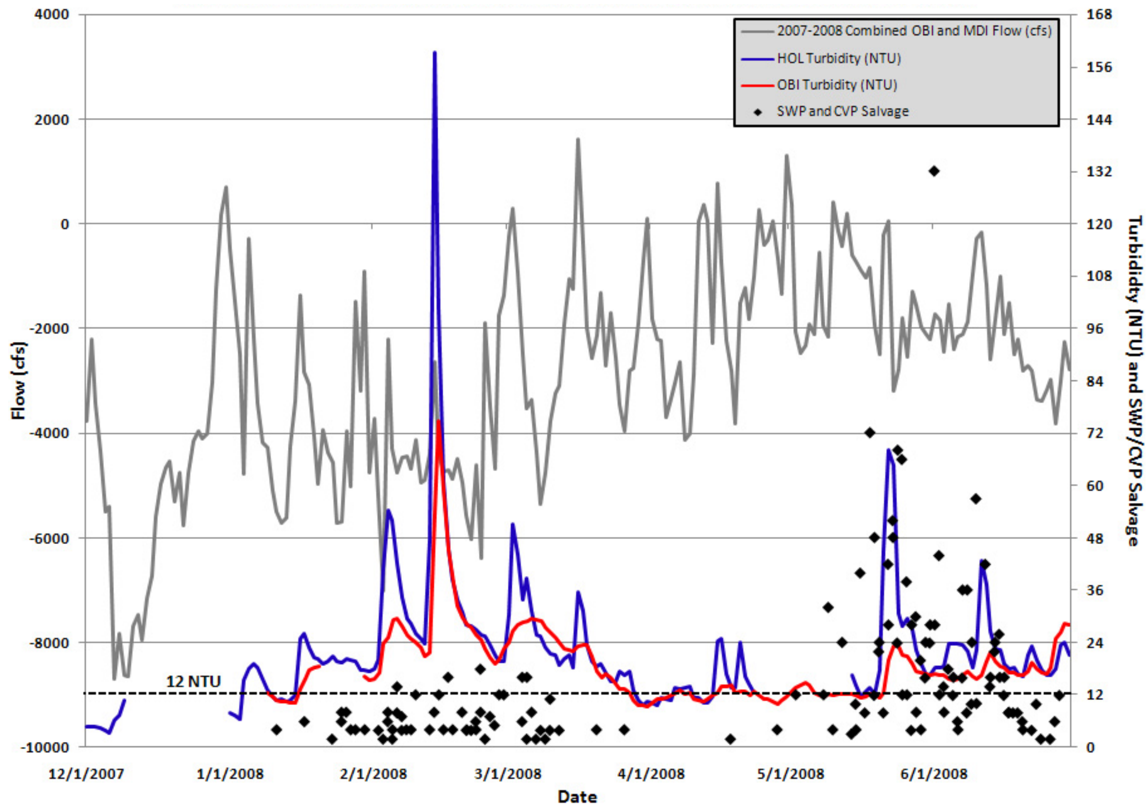

Figure note: HOL = Holland Cut near Bethel Island
OBI = Old River at Bacon Island